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THE EFFECTS OF MOISTURE ON THE MECHANICAL PERFORMANCE OF T300 GRAPHITE/GLASS/EPOXY HYBRID COMPOSITES

Final Report

(September 1, 1974 to November 30, 1975)

December, 1975

by

K. E. Hofer, Jr.
L. C. Bennett

IIT Research Institute

for

Department of the Navy
Naval Air Systems Command
Washington, D.C. 20360

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Final Report

THE EFFECTS OF MOISTURE ON THE MECHANICAL PERFORMANCE OF T300 GRAPHITE/GLASS/EPOXY HYBRID COMPOSITES

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Thornel 300 Graphite/S-Glass Rovings/Narmco 5208 epoxy hybrid composites were investigated to establish the effect of temperature and moisture on the fatigue, impact and residual (after cycling) mechanical properties. The preconditioning treatments were high humidity (98% RH at 120°F) coupled with and without thermal shocks. The stress cycling was accomplished at 75°F, 98% RH and ϕ = 1800 cpm. (cont. next page)

Block No. 20 - Abstract (cont.)

The results showed that hybrid graphite/glass/epoxy composites can be manufactured with properties at least as good as the high modulus all-graphite/epoxy composites and at considerably reduced costs over an all-graphite composite. Overall, the hybrid composites not only can produce cost effective composites but actually can possess mechanical properties considerably improved over the single phase systems.

A comparison of the all glass systems and the hybrid glass/graphite system shows that the transverse fatigue strengths are higher for the all-glass composite, where the interfacial bonding is expected to be good, than for the hybrid system where some graphite/epoxy interfacial bonds are present. The 1000 hour high moisture exposures on these two systems, however, result in a very similar residual fatigue strength. This is taken to indicate that the principal degradatory mechanism of moisture is on the interface between the fiber and the matrix and that the graphite composite degradation will be no worse than that for glass composites.

The 1000 hours at 98% RH exposure should be considered as the one for accelerated aging programs since it points out the fatigue behavior of the composites most clearly. Graphite/epoxy, glass/epoxy and graphite/glass/epoxy composites appear to show fiber/matrix decoupling during fatigue causing an increase in the 0° fatigue performance, a decrease in the 90° fatigue resistance and a mixed modal behavior in quasi-isotropic laminates. The residual elastic modulus of graphite/epoxy and glass/graphite/epoxy hybrid composites remains constant at least out to the 10^7 cyclic life level even after high humidity cycling. The elastic strength decreased as the cyclic exposure increases and Poisson's ratio for the 0° material increases slightly with added stress cycling.

The impact resistance of hybrid glass/graphite/epoxy composites is improved over the all-graphite/epoxy composites to a level frequently as good as the all-glass/epoxy composites. The presence of moisture does not degrade the impact resistance of either single phase or hybrid composites and frequently improves the impact energy to fracture as the resin plasticizes.

FOREWORD

This technical report was prepared by the Mechanics of Materials Research Division of the IIT Research Institute, Chicago, Illinois. The authors include K. E. Hofer, Jr. responsible for overall program management and acting as the principal investigator, L. C. Bennett, responsible for the fatigue testing aspects of this effort. Other supporting staff for this effort include Renard Porte, impact testing engineer.

The effort described was conducted in support of materials studies for the Naval Air Systems Command during the period September 1, 1974 through November 30, 1975. M. Stander (AIR 52032D) was the program monitor on behalf of the Naval Air Systems Command.

This report was submitted by the authors January, 1976.

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SECTION I

1.0 INTRODUCTION

The objective of this program was to establish the effect of high-humidity on the mechanical performance of graphite/glass/epoxy hybrid composites suitable for application to the stringent requirements of Naval aircraft.

This program was designed to meet the objectives of the program. The fatigue program, shown in Table I, contains various environmental preconditioning treatments which are purportedly degradative to advanced fiber composites. In addition to the generation of S-N data on these composites, the residual mechanical properties, namely strength, modulus and Poisson's ratio as a function of the load cycles was obtained as shown in Table I.

Table II presents the impact resistance test program aimed at establishing the enhancement of impact resistance that is expected when glass/graphite/epoxy hybrids are used instead of basic graphite/epoxy composites.

TABLE I

TENSILE FATIGUE TESTING PROGRAM AFTER VARIOUS HUMIDITY CONDITIONING TREATMENTS

MATERIAL	PRECONDITION TREATMENT	0°		90°	QUASI-ISOTROPIC	
		SN	RESID. σ	SN	SN	RESID. σ
S-Glass/ Narmco 5208	Baseline	10	5	5	10	5
	500 Hrs/98% RH	5	-	5	5	-
	1000 Hrs/98% RH	5	5	5	5	5
	MAC AIR Cycle	5	-	5	5	-
T300 Graphite/ Narmoc 5208	Baseline	*	5	*	10	5
	500 Hrs/98% RH	*	-	*	5	-
	1000 Hrs/98% RH	*	5	*	5	5
	MAC AIR Cycle	*	-	*	5	-
Hybrids 1:1#	Baseline	10	5	5	10	-
	500 Hrs/98% RH	5	-	-	-	-
	1000 Hrs/98% RH	5	5	5	5	-
	MAC AIR Cycle	5	-	-	-	-
Hybrids 2:1#	Baseline	10	5	5	10	-
	500 Hrs/98% RH	5	-	-	-	-
	1000 Hrs/98% RH	5	5	5	5	-
	MAC AIR Cycle	5	-	-	-	-
Hybrids 3:1#	Baseline	10	-	-	10	-
	500 Hrs/98% RH	5	-	-	-	-
	1000 Hrs/98% RH	5	-	-	5	-
	MAC AIR Cycle	5	-	-	-	-

Ratio of Graphite to Glass

* Data Already Available in Ref. 1

TABLE II

LATERAL IMPACT TEST PROGRAM AFTER VARIOUS HUMIDITY CONDITIONING TREATMENTS

MATERIAL	PRECONDITIONING	0°	$[0/90]_{S8}$	QUASI-ISOTROPIC
S-Glass/ Narmco 5208	Baseline	10	10	10
	500 Hrs/98% RH	5	5	5
	1000 Hrs/98% RH	5	5	5
	MAC AIR Cycle	5	5	5
T300/Narmco 5208	Baseline	10	10	10
	500 Hrs/98% RH	5	5	5
	1000 Hrs/98% RH	5	5	5
	MAC AIR Cycle	5	5	5
Hybrids 1:1*	Baseline	5	5	5
	500 Hrs/98% RH	5	5	5
	1000 Hrs/98% RH	5	5	5
	MAC AIR Cycle	5	5	5
Hybrids 2:1*	Baseline	5	5	5
	500 Hrs/98% RH	5	5	5
	1000 Hrs/98% RH	5	5	5
	MAC AIR Cycle	5	5	5
Hybrids 3:1*	Baseline	5	5	5
	500 Hrs/98% RH	5	5	5
	1000 Hrs/98% RH	5	5	5
	MAC AIR Cycle	5	5	5

*Ratio of Graphite Plies to Glass Plies

SECTION II

2.0 MATERIALS AND FABRICATION

In consideration of the Navy's needs for information on the most current and most promising advanced composite materials, a survey of graphite/epoxy systems was made. The Thornel 300/Narmco 5208 prepreg system was selected on the basis of that review for this study. S-Glass rovings have been frequently studied in the past for their application to aerospace components. Thus the second fiber phase was selected to be S-Glass rovings. The complete ternary system was T300 Graphite/S-Glass rovings/Narmco 5208. In a previous study by Rao and Hofer (Ref. 1) the importance of properly interleaving the layers of glass prepreg and graphite prepreg was demonstrated. Thus in order to avoid the high shear stresses that occur when the core-shell methods are used, an even distribution of the plies throughout the laminate was utilized for the current study. The cost effectiveness of glass is best realized when the stiffer graphite prepreg layers are utilized as the surface plies. Thus the predominance of 0° graphite plies in the outer layers of the composites used in this program.

Table III shows the ply stacking sequences used for the basic and hybrid composites used in the fatigue and lateral impact studies (see Table I) and Table IV shows the additional crossply (0-90) laminates used in the lateral impact studies.

The quasi-isotropic hybrid composites stacking arrangements are more clearly seen by reference to Figs. 1-3. The interleaving technique requires a distribution of graphite and glass plies.

Thus as seen in Fig. 1 the 0° graphite ply is on both outside faces. Symmetry is also maintained. The maximum cross-

TABLE III

MATERIAL AND STACKING ARRANGEMENTS FOR THE BASE AND HYBRID COMPOSITES MATERIALS USED IN THE FATIGUE TEST PROGRAM

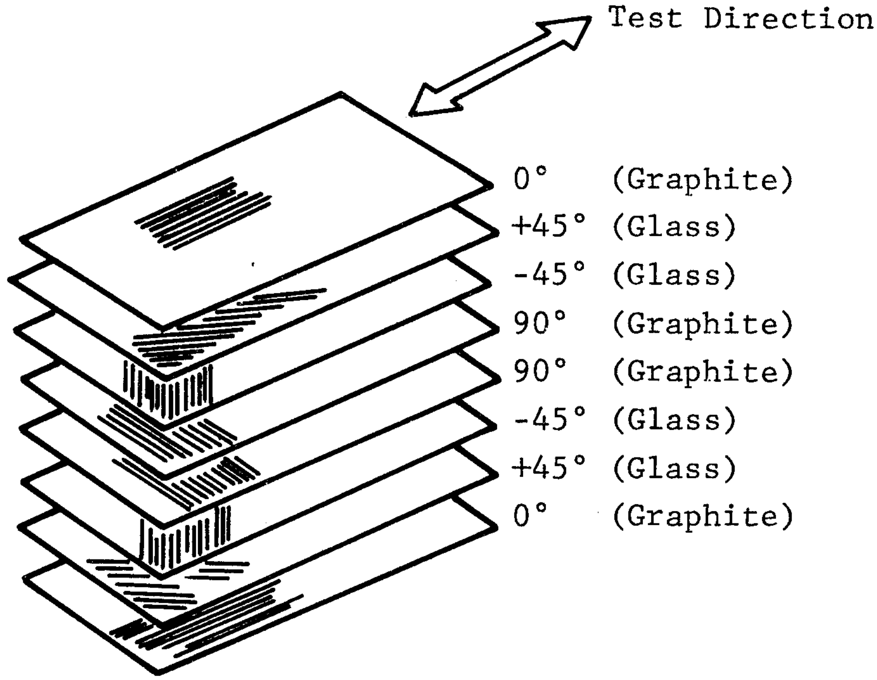
Plate Type	Graphite/Glass Ratio	No.	Ply by Ply Orientation For Hybrid Composites R = Graphite; L = Glass
0°	0:1	6	[0/0/0/0/0/0]
	1:0**	6	[0/0/0/0/0/0]
	1:1	8	[0R/0L/0R/0L/0L/0R/0L/0R]
	2:1	6	[0R/0L/0R/0R/0L/0R]
	3:1	8	[0R/0L/0R/0R/0R/0R/0L/0R]
90°	0:1	8	[90/90/90/90/90/90/90/90]
	1:0**	8	[90/90/90/90/90/90/90/90]
	1:1	8	[90R/90L/90R/90L/90L/90R/90L/90R]
	2:1	9	[90R/90L/90R/90R/90L/90R/90R/90L/90R]
	3:1	8	[90R/90L/90R/90R/90R/90R/90L/90R]
Q.I.*	0:1	8	[0/45/135/90/90/135/45/0]
	1:0	8	[0/45/135/90/90/135/45/0]
	1:1	8	[0R/45L/135L/90R/90R/135L/45L/0R]
	2:1	12	[0R/90R/45L/135L/90R/0R/0R/90R/135L/45L/90R/0R]
	3:1	16	[0R/90R/0R/90R/45L/135L/90R/0R/0R/90R/135L/45L/90R/0R/90R/0R]

* Quasi Isotropic, ** Data Already Available

TABLE IV

MATERIAL AND STACKING ARRANGEMENTS FOR THE BASE AND HYBRID COMPOSITE MATERIALS USED IN THE LATERAL IMPACT STUDIES

Plate Type	Graphite/Glass Ratio	Ply by Ply Orientation No.	Ply by Ply Orientation For Hybrid Composites R = Graphite, L = Glass
[0/90]	1:0	8	[0/90/0/90/90/0/90/0]
	0:1	8	[0/90/0/90/90/0/90/0]
	1:1	8	[0R/90L/0L/90R/90R/0L/90L/0R]
	2:1	12	[0R/90R/0L/90L/0R/90R/90R/0R/90L/0L/90R/0R]
	3:1	8	[0R/90R/0L/90R/90R/0L/90R/0R]

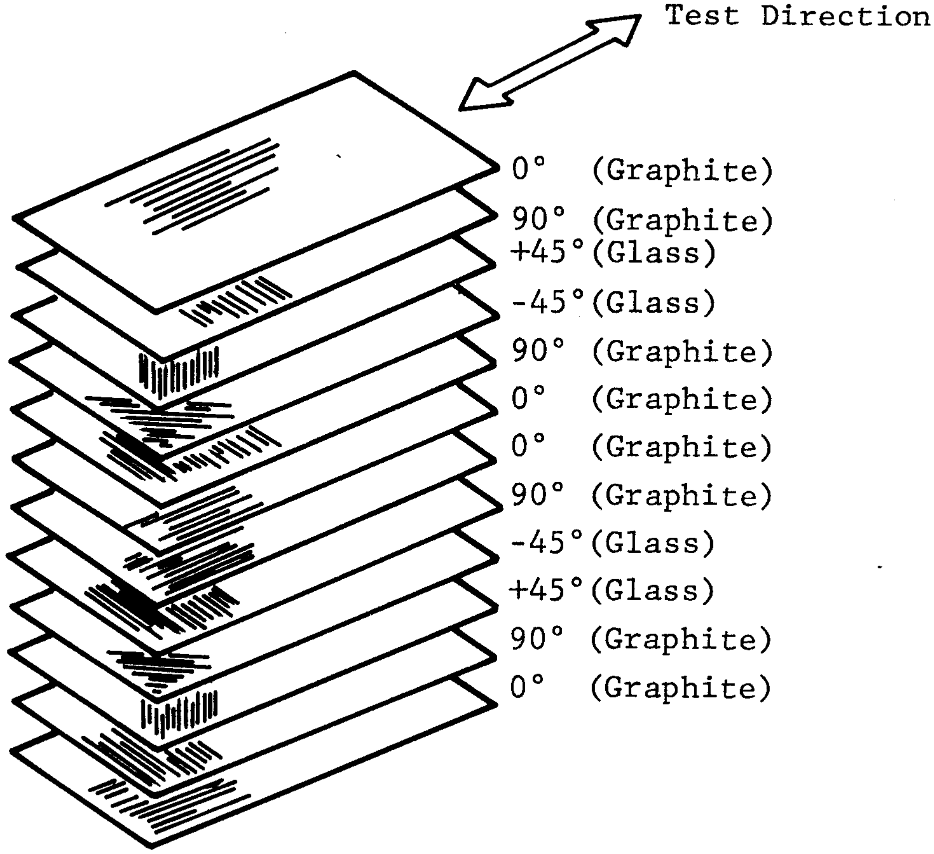


Designation: $[0°R/\pm 45°L/90°R_2/\mp 45°L/0°R]$

Ratio of Graphite to Glass = 1:1

Ratio of Graphite 0° to Graphite 90° = 1:1

Figure 1 Stacking Arrangement for the Quasi Isotropic 1:1 (Graphite Plies/Glass Plies) Hybrid Composites Used in Fatigue Studies.

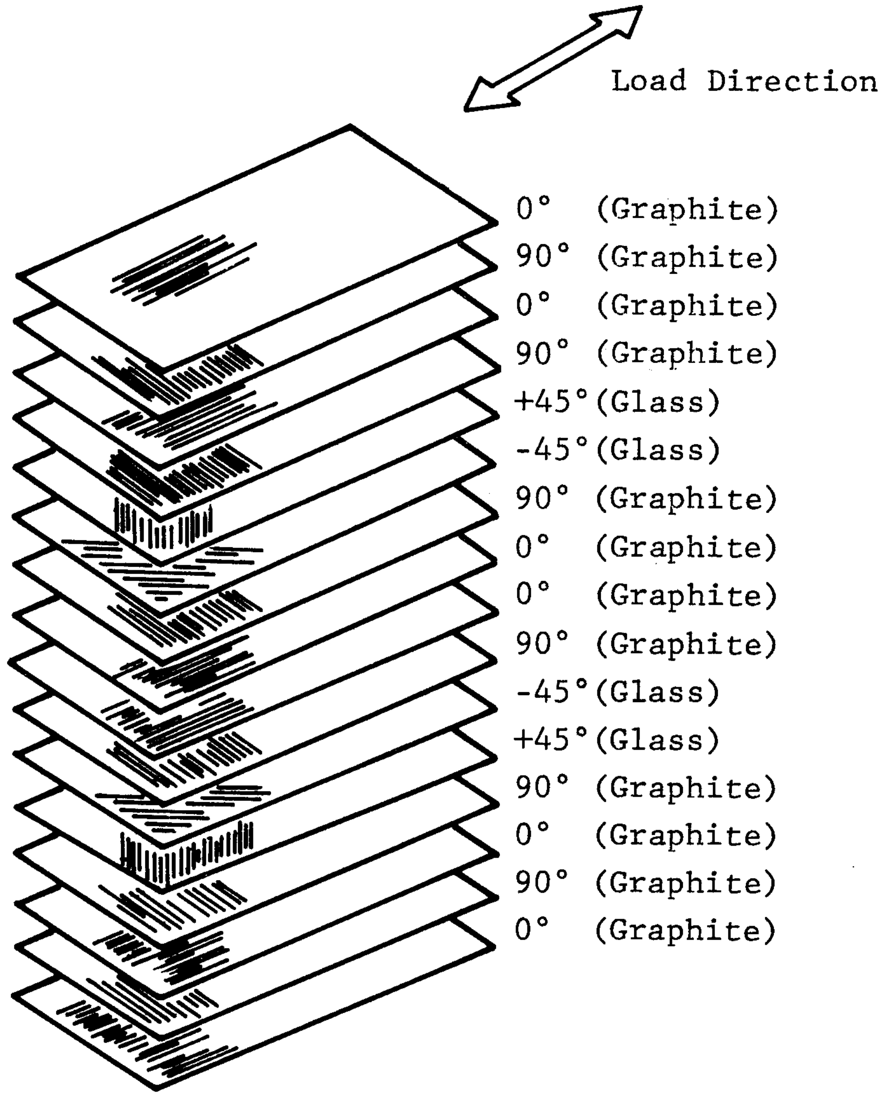


Designation: $[0°R/90°R/\pm45°L/90°R/0°R_2/90°R/\mp45°L/90°R/0°R]$

Ratio of Graphite to Glass = 2:1

Ratio of Graphite 0° to Graphite 90° = 1:1

Figure 2 Stacking Arrangement for the Quasi-Isotropic 2:1 (Graphite Plies to Glass Plies) Hybrid Composite Used in Fatigue Studies.



Designation: $[0°R/90°R/0°R/90°R/\pm45°L/90°R/0°L_2/90°R/\mp45°L/90°R/0°R/90°R/0°R]$

Ratio of Graphite to Glass = 3:1

Ratio of Graphite 0° to Graphite 90° = 1:1

Figure 3 Stacking Arrangement for the Quasi-Isotropic 3:1 (Graphite Plies to Glass Plies) Hybrid Composite Used in Fatigue Studies.

ply compliance is maintained by the four ± 45 S-Glass plies. There are four transitional zones of glass to graphite.

Figure 2 shows the 2:1 (Graphite to Glass Ratio) hybrid composite with 12 plies, four transition zones and a ratio of graphite 0° to graphite 90° of 1:1 just as in the 1:1 quasi-isotropic hybrid composite. Again the 0° graphite plies lie on the outside of the composite stack and the stack is balanced symmetric about the central plane in both material and orientation.

The 3:1 quasi-isotropic hybrid composite contains 16 plies as shown in Fig. 3, has four transition zones, graphite 0° to 90° layers are again maintained in the ratio of 1:1 and the graphite 0° plies lie on the outside of the balanced symmetric composite.

Complete details of the fabrication process are described in Appendix I to this report.

SECTION III

3.0 ENVIRONMENTAL EXPOSURES

The most important single variable in the Naval environment has been shown to be the presence of moisture. Moisture degrades most of the epoxy resins useful for composite laminates at elevated temperatures as has been repeatedly demonstrated in the literature (references 5-10).

These degradatory mechanisms have serious implications wherever advanced composites either single fiber types or hybrids are employed. For this reason the effects of both long term moisture exposure and of the degradation that takes place when the humidity is coupled with temperature variations becomes important.

This program employed both steady state long term exposure to constant high humidity and a thermo-humidity cyclic exposure to simulate some of the aerospace environment where high and low temperatures are encountered during a flight spectrum. No attempt was made to define a precise spectrum based on a specific aircraft although this particular task should be considered for future investigations. A description of the conditioning treatments follows.

3.1 Steady State Humidity Conditioning

The steady state humidity conditioning of specimens includes 500 and 1000 hr. (3 weeks and 6 weeks) exposure to 98% ± 2% relative humidity and 120°F. This exposure is the same as that recommended by Mil Handbook 17.

The specimens which are subjected to humidity exposure were prepared as follows:

1) All specimens were finish machined and the tabs were bonded prior to initiation of the preconditioning treatment. For room temperature tests subject to prior humidity conditioning the adhesive was FM 1000.

2) The samples were then coated with Navy specification epoxy primer and polyurethane topcoat on the sides and all edges as well as the tabs of the specimens. The materials used were identified as primer: Epoxy, Polyamide. Topcoat: Polyurethane, Component(1) 8010-00-181-8150 base, Component(2) 8010-00-181-8150 hardener.

3) The samples were individually weighed prior to insertion in the chamber (Webber Environmental Chamber).

4) Each sample was arranged in the chamber to permit maximum exposure to the moisture-laden air as it flowed from the inlet orifice to the chamber.

These steps were followed to permit rapid testing of the samples after removal from the chamber. Upon removal from the chamber, the specimens were reweighed and the moisture weight gains were noted. The tests generally could not be performed immediately due to machine unavailability, and therefore the samples were sealed in a protective vinyl, moisture proof container. These samples were then reweighed, prior to testing, to determine if moisture loss had occurred. Generally no moisture was lost in this way.

3.2 Thermo-Humidity Cycle

Table I and II listed a thermo-humidity cyclic conditioning exposure, as well as the steady state exposure, this thermo-humidity cycle was selected from a review of previous aerospace practices. The Webber Environmental Chamber was again used for the humidity exposure.

The details of the Thermo-Humidity cycle employed are: (1) The total time period for the cycle was 500 hours. (2) During this period, the specimens were placed in the environmental chamber and exposed to a relative humidity of $98^{\circ} \pm 2\%$ at $120^{\circ} \pm 5^{\circ}F$ except for one and one half hour each work day of the week when they were taken out and subjected to thermal shock. (3) This shock treatment consisted of exposing the specimens for one hour at $-65^{\circ}F$ in a cold chamber followed by an exposure of one half hour at $350^{\circ}F$ in an oven. (4) During the weekend the specimens remained in the environmental chamber continuously exposed to the humidity conditions mentioned above.

The frost conditions on the specimens after exposure to $-65^{\circ}F$ were noted, but no specimen delamination occurred after removal from the $350^{\circ}F$ portion of the cycle.

The test specimens were made ready for testing as soon as possible after removal from the test chamber as was done for the steady state humidity conditioning exposures and where machines were unavailable the same bagging precautions employed above were employed.

3.3 Effects of Humidity Conditioning

The steady state exposure of the Thornel 300 Graphite/ Narmco 5208, S. Glass/Narmco 5208 and T300 Graphite/S-Glass/ Narmco 5208 Hybrid moisture pickup by the exposed coated samples. Figures 4 to 8 show the moisture pickup versus time. The curves are an aggregate of moisture pickup for three orientations, three thicknesses (ply thickness), and two widths of sample. Thus, the ratio of surface area to volume of the samples varies over a substantial range and the ratio of exposed fiber ends to surface area also varies.

In plotting these gains for the three different humidity environments account was taken of the various orientations, specimens sizes, etc. (see legend on each figure). Thus while the surface area to volume ratio for a twelve ply Quasi-Isotropic* laminate may remain virtually the same as a six ply $[0]_6$ laminate, the exposed fiber ends on the quasi-Isotropic laminate provide more potential entry paths for moisture to enter the specimen.

Groups of specimens of a given type were inserted at various times into the humidity chamber during their appropriate schedules. Therefore several different points may appear at the same total exposure time. Each point represents an average of from 5 to 10 specimens of the type indicated. Thus the variability of moisture pickup from group to group can be obtained from Figures 4 to 8 as well.

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*Quasi-Isotropic lamina are of the form $[0^\circ/\pm45^\circ/90^\circ{}_2/\mp45^\circ/0]$.

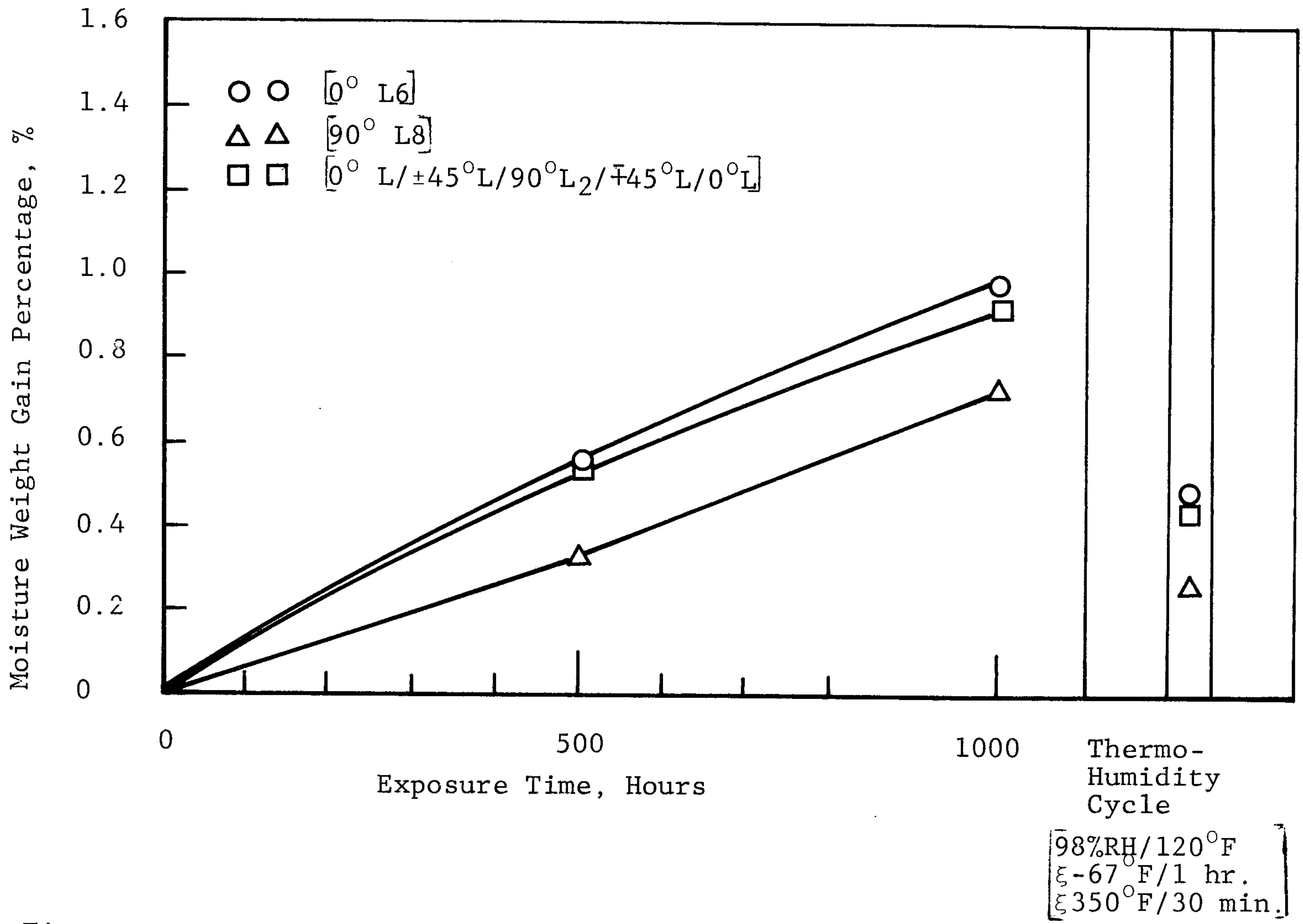


Fig. 4 Moisture Weight Gain Percentages for Accelerated Aging Exposure at 98% RH and 120°F of S-Glass/ Narmco 5208 Composites.

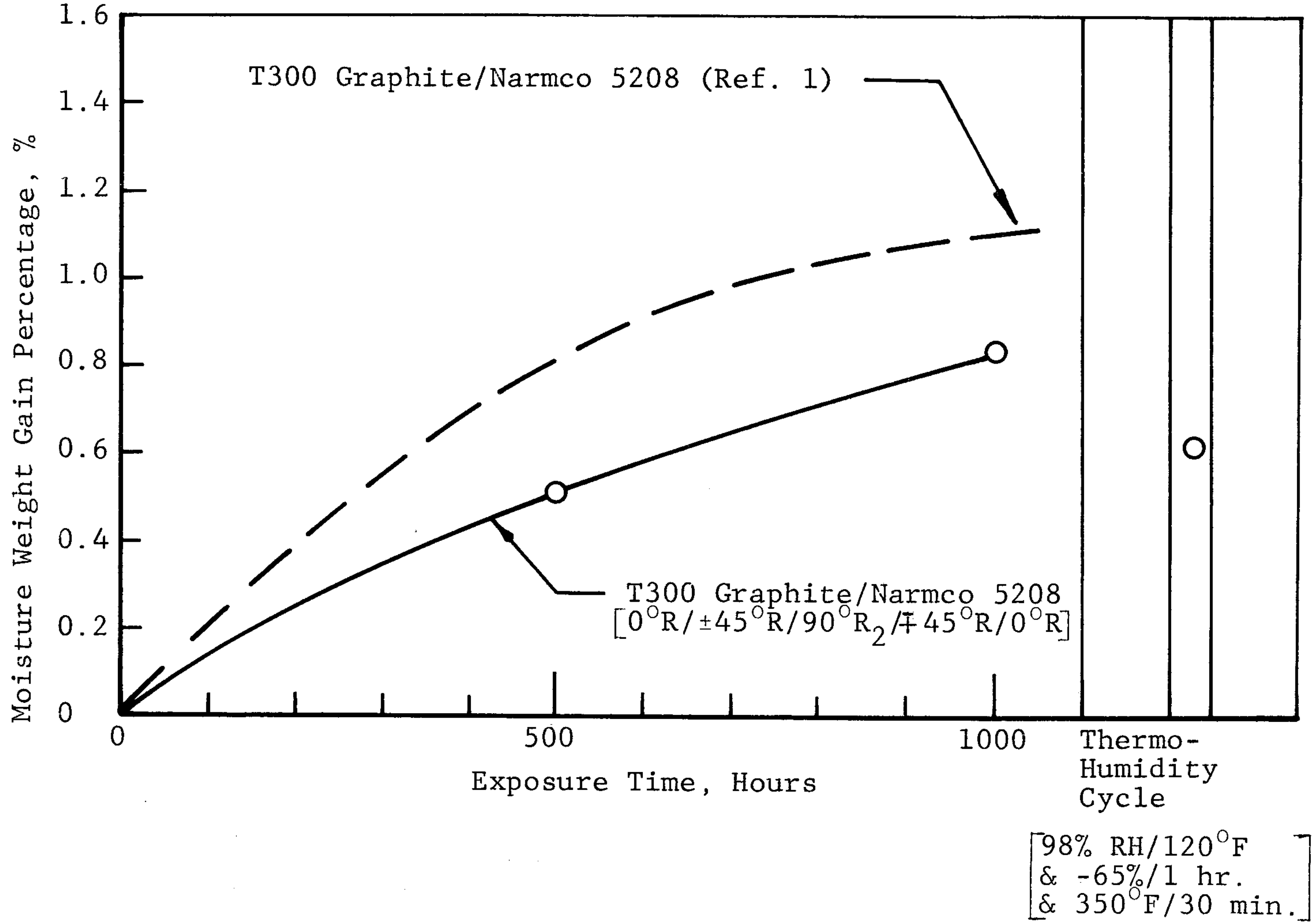


Figure 5 Moisture Weight Gain Percentage for Accelerated Aging Exposure at 98% RH and 120°F of T300 Graphite/ Narmco 5208 Composites.

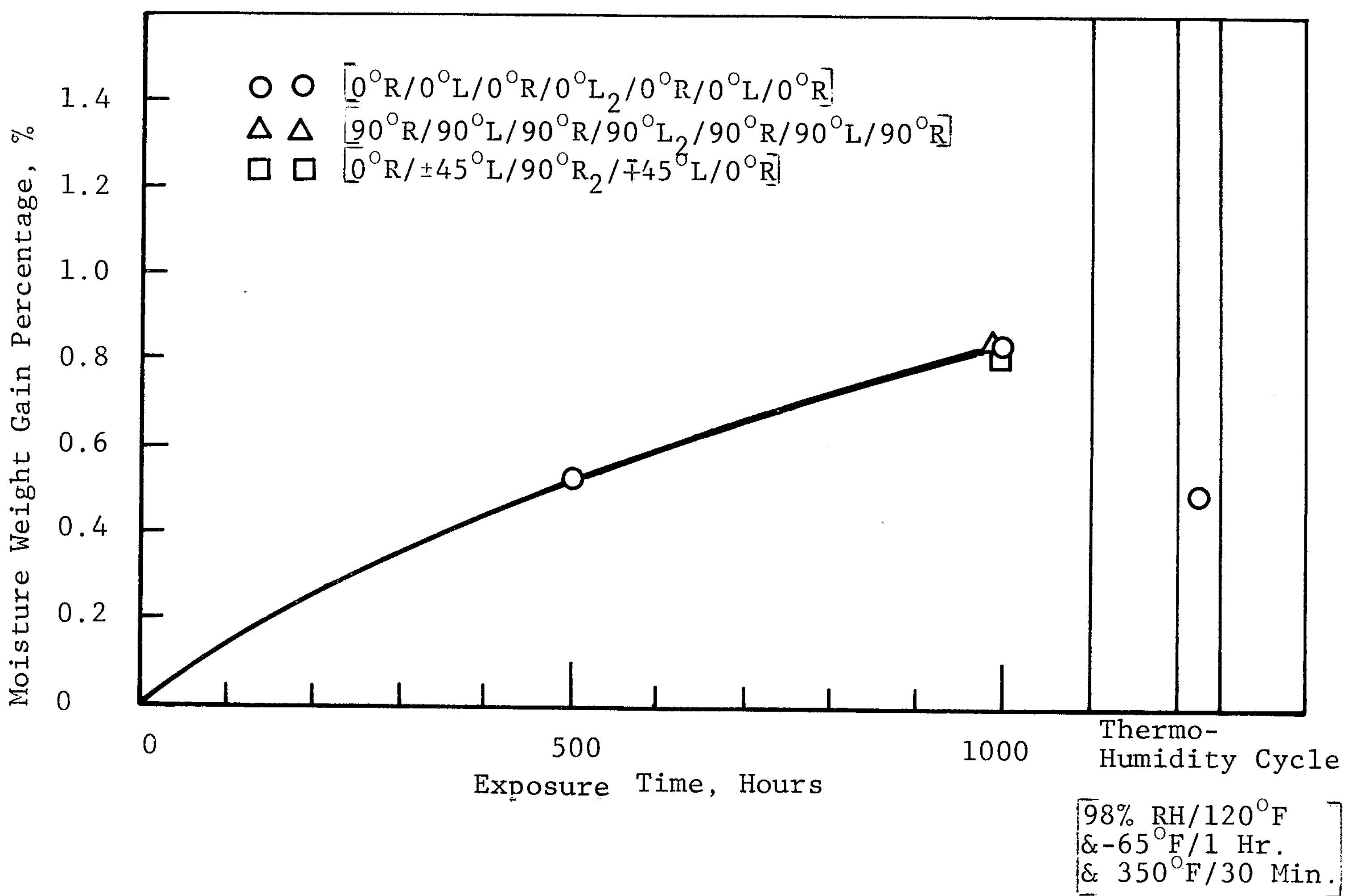


Fig. 6 Moisture Weight Gain Percentages for Accelerated Aging Exposure at 98% RH and 120°F of T300-Graphite/S-Glass/Narmco 5208 Hybrid Composites (1:1 Graphite to Glass Ratio)

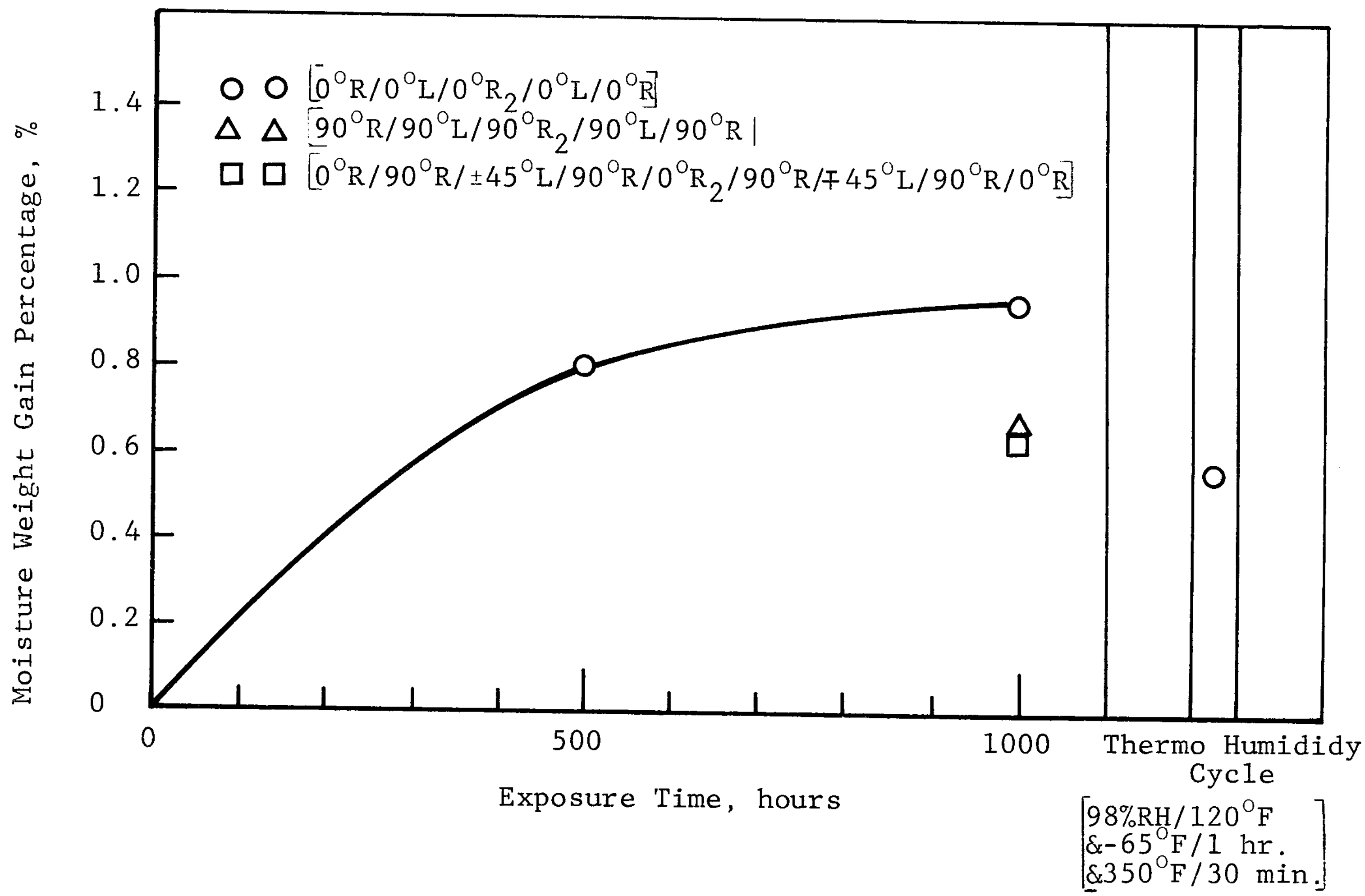


Fig. 7 Moisture Weight Gain Percentages for Accelerated Aging Exposure at 98% RH and 120°F of S-Glass/T-300 Graphite/ Narmco 5208 Hybrid Composite (2:1 Graphite to Glass Ratio)

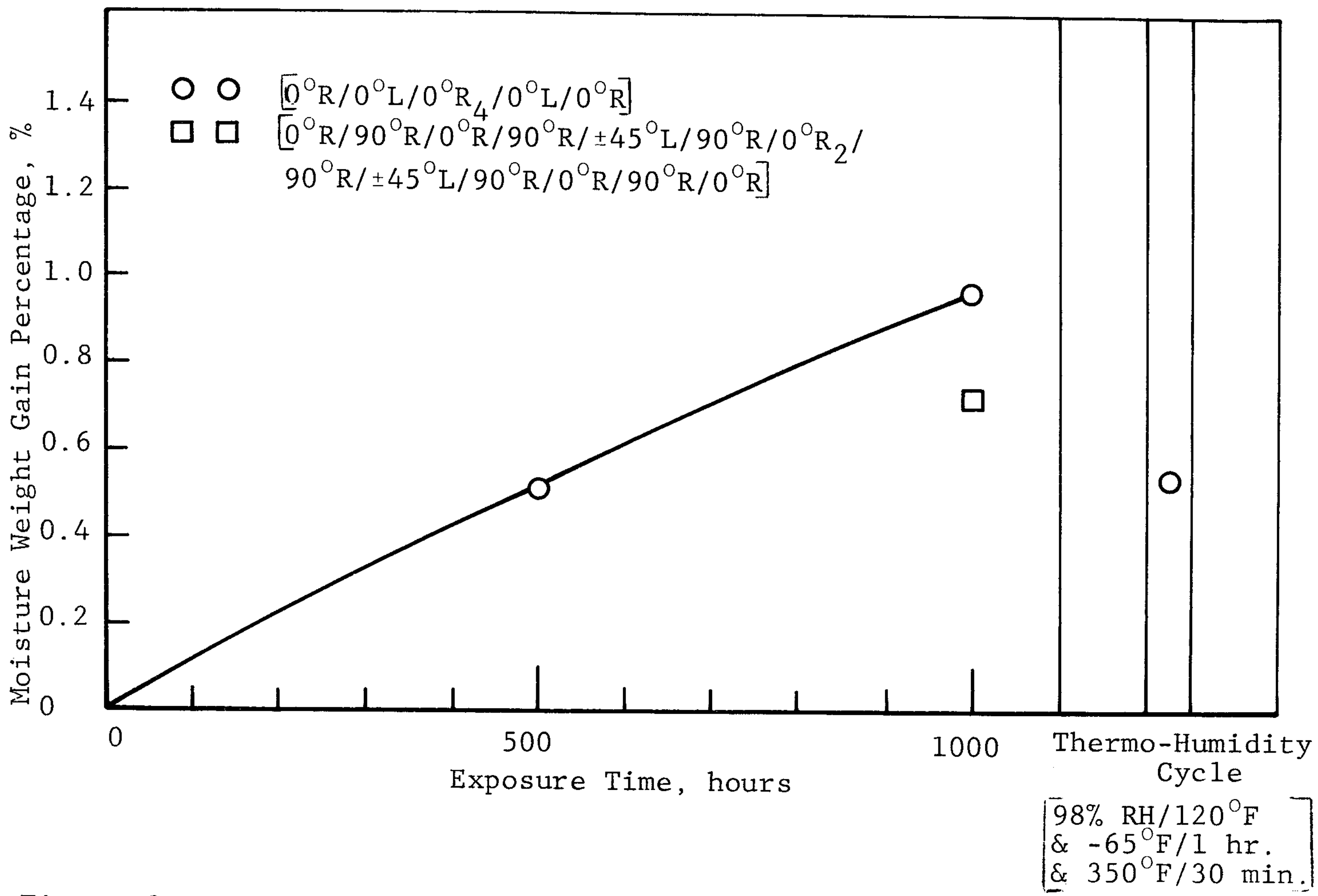


Figure 8 Moisture Weight Gain Percentages for Accelerated Aging Exposure at 98% RH and 120°F of S-Glass/T300 Graphite/Narmco 5208 Hybrid Composites (3:1 Graphite to Glass Ratio)

In general, the Thermo-Humidity cycle data corresponds to that of approximately 500 hours of constant humidity exposure, as described in Reference 1 this correspondence of the cyclic humidity conditioning to the steady exposure is related to the total exposure time to high humidity conditions.

In Figure 4, it can be seen that 500 hours of exposure to 98% RH and 120°F corresponds to a moisture pickup of approximately 0.6% for 0° and quasi-isotropic coupons and of about 0.4% for 90° (transverse) coupons when glass is the reinforcing fiber. The moisture pickups at 500 hours by the basic T-300 quasi-isotropic laminate was approximately 0.5%. This is compared to an overall pickup in a previous study by Hofer et al (Reference 1) of approximately 0.8% at 500 hours. Thus the T-300 Graphite/Narmco 5208 laminates in this study showed slightly less moisture pickup than the glass and somewhat less than the aggregate average of several laminate orientations in the previous study. This is attributed to the moisture barrier afforded by the polyurethane paint which probably inhibited moisture absorbtion, transport and locking. (The previous study, Reference 1, utilized only uncoiled or bare composites). However the differences at 100 hours are percentagewise less between the pickups attained in this study and that attained in the previous study. It is apparent that once the moisture absorbtion and transport mechanisms are operative, the rate of pickup for coated samples is essentially the same as for uncoated samples.

The 1:1 hybrid composite moisture pickup shown in Figure 6 shows approximately the same results as for the S-glass/Narmco 5208 basic composite. At 1000 hours virtually all the basic and hybrid composites showed an average of approximately 1.0% absorbed moisture. One anomaly at 500 hours in the 2:1 hybrid occurred. The high (0.8%) moisture weight gain shown may not be realistic in terms of the overall behavior of the other composites and may just represent an exceptionally high set of data since it represents only one lot of five data points.

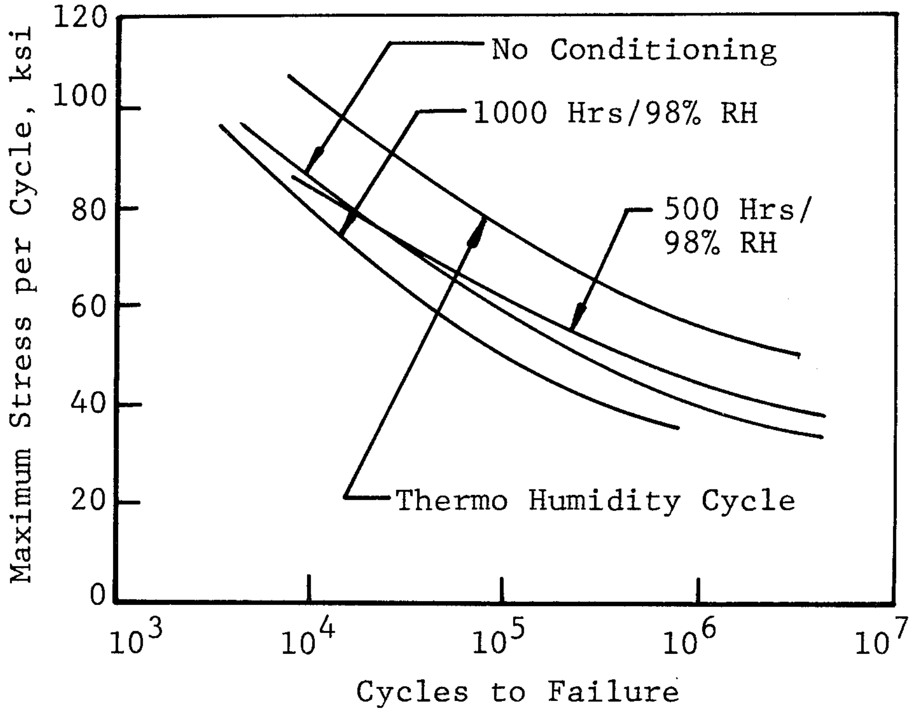
4.0 FATIGUE BEHAVIOR OF HYBRID COMPOSITES

The fatigue testing program described in Table I was performed using an SF-10-U Sonntag Universal Fatigue Testing Machine. The frequency of cycling was 30 Hertz (1800 cpm). All materials were tested in a Tension-Tension load cycle (R=0.1) where

$$R = \frac{\text{Minimum Stress per Cycle}}{\text{Maximum Stress per Cycle}}$$

All specimens were bagged using a polyethylene bag throughout the fatigue testing, so as to prevent the loss of moisture occurring during the fatigue test due to test artifacts such as specimen heatup, etc. The overall individual fatigue specimen test results are given In Appendix II to this report (See Table VIII and Figures 61 to 97). This section will be entirely devoted to a discussion of these results. Figures 9, 10, and 11 show the fatigue behavior of the 100% S-Glass/Narmco 5208 composite materials and how they are influenced by the prior high humidity conditioning. Figure 9 shows the behavior of 0° glass composites. Note that some degradation from the unconditioned state occurs after 1000 hours exposure even though little or no effect was noted after 500 hours. Almost 1% moisture had been absorbed after 1000 hours although only 0.5% had been absorbed after 500 hours. (See Figure 1). Some of the moisture content may also have been absorbed by the coating as well. The thermo-humidity cycle exposure producing surprising results, showing a slight increase in the 0° fatigue resistance. The transverse fatigue strengths were not affected at all by most of the conditionings, but the 1000 hours exposure reduced the overall fatigue capacity by 25%. The thermo-humidity cycle did not appear any worse than the original uncon-ditional fatigue resistance or that after exposure to 500 hours at 98% RH and 120°F. The quasi-isotropic behavior which included the effects of the prior humidity conditioning on both the 0° and fatigue resistances of S-Glass/Narmco 5208, was generally as good or better than the original unconditioned material.

There was no effect whatever on the fatigue resistance of the pure graphite/epoxy composites studied, as a result of the high humidity exposures. (See Figure 12). This corresponds



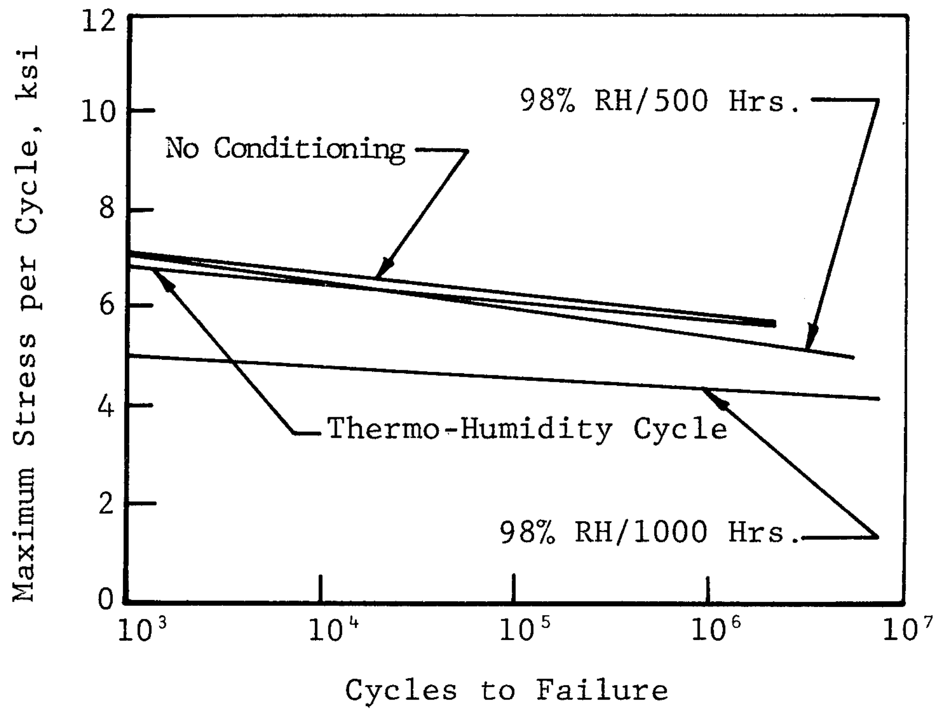
Orientation: $[0°L_6]$

Temperature: 70°F

Stress Cycle: R =0.1/T=70°F/ϕ=30 Hertz

Percentage Graphite" 0%, by plies

Figure 9 Comparative Fatigue S-N Behavior for S-Glass/ Narmco 5208 Composites After Exposure to Various Hostile Environments.



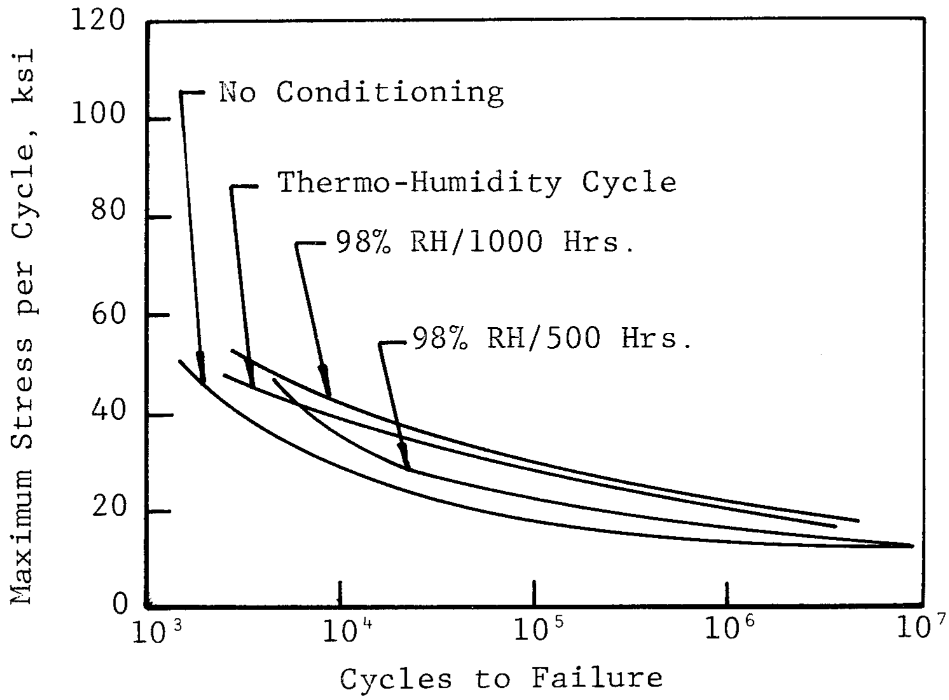
Orientation: $[90^{\circ}L_8]$

Temperature: $70^{\circ}F$

Stress Cycle: $R=0.1/T=70^{\circ}F/\phi=30$ Hertz

Percentage Graphite: 0%, by plies

Figure 10 Comparative Fatigue S-N Behavior for S-Glass/ Narmco 5208 Composites after Exposure to Various Hostile Environments.



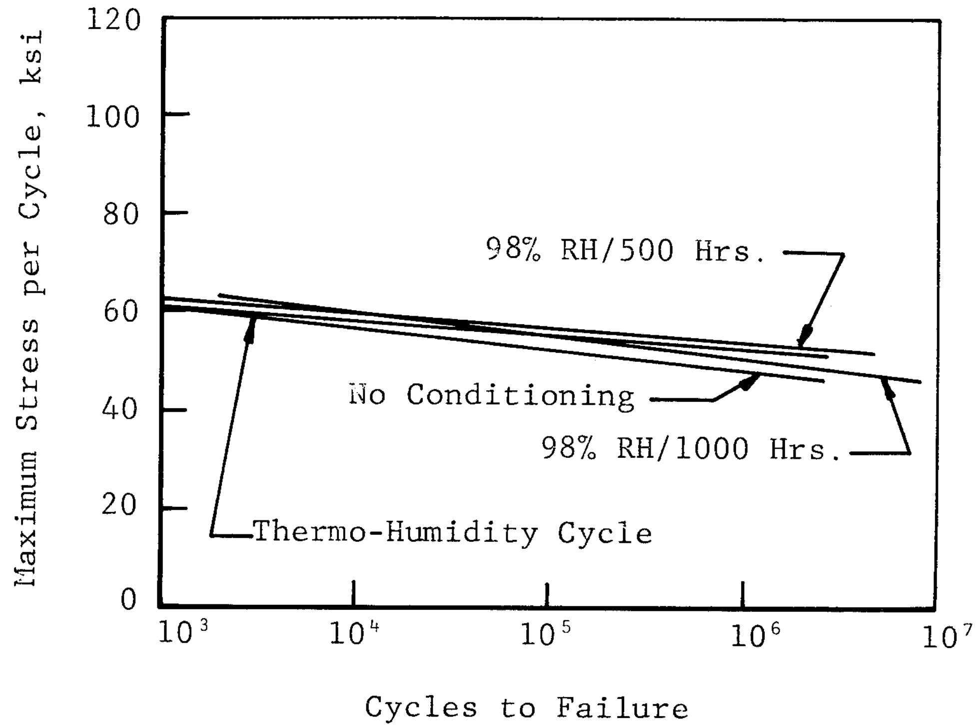
Orientation: $[0^{o}L/\pm45^{o}L/90^{o}L_2/\mp45^{o}L/0^{o}L]$

Temperature: $70^{o}F$

Stress Cycle: $R=0.1/T=70^{o}F/\phi=30$ Hertz

Percentage Graphite: 0%, by plies

Figure 11 Comparative Fatigue S-N Behavior for S-Glass/ Narmco 5208 Composites after Exposure to Various Hostile Environments.



Orientation: $[0^{\circ}R/\pm45^{\circ}R/90^{\circ}R_2/\pm45^{\circ}R/0^{\circ}R]$

Temperature: $70^{\circ}F$

Stress Cycle: $R=0.1/T=70^{\circ}F/\phi=30$ Hertz

Percentage Graphite: 100%, by plies

Figure 12 Comparative Fatigue S-N Behavior for T-300 Graphite/Narmco 5208 Composites after Exposure to various Environments.

previous data on 0°, 90° and $[0^{\circ}/\pm45^{\circ}/0^{\circ}/90^{\circ}/0^{\circ}/\mp45^{\circ}/0^{\circ}]$ laminates by this investigator (see Reference 1).

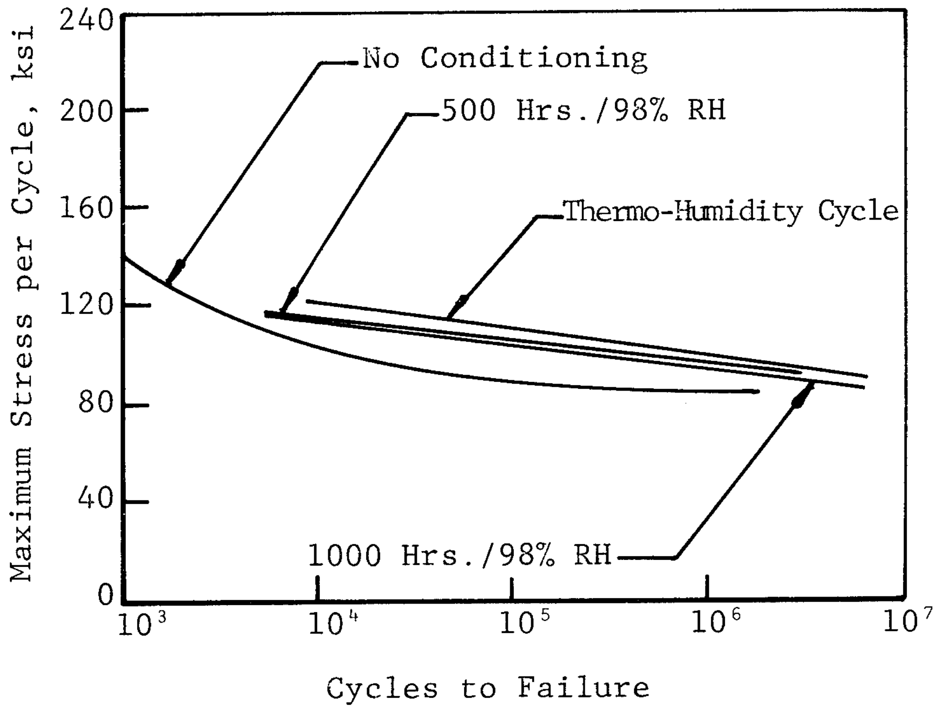
Figures 13-15 show the behavior of T300 graphite/S-Glass/Narmco 5208 hybrid composites with a ratio of 1:1 (graphite to glass) after prior exposure to a variety of conditioning treatments. Only slight or no reduction in the fatigue performance of these hybrids came about as a result of these exposures.

The 2:1 graphite to glass hybrid composite comparisons are shown in Figures 16 through 18. The 2:1 0° behavior is quite like that for all glass 0° composites (compare Figures 16 and 9) and in particular it should be noted that not only did the thermohumidity cycle not reduce the fatigue resistance of this hybrid but actually enhanced it. This occurred despite the fact that the total moisture absorbed for the 2:1 0° hybrid exceeded 0.6% (see Figure 7). Little or no effect was observed for the 90° and quasi-isotropic 2:1 hybrid composites (see Figures 17 and 18).

Figures 19 and 20 show the results for the 3:1 hybrid composites after the prior conditioning. No effect was observed for the quasi-isotropic 3:1 hybrid $[0^{\circ}R/90^{\circ}R/0^{\circ}R/90^{\circ}R/\pm45^{\circ}L/90^{\circ}R/0^{\circ}R_2/\pm90^{\circ}R/\mp45^{\circ}L/90^{\circ}R/0^{\circ}R/90^{\circ}R/0^{\circ}R]$ although a distinct improvement in all 0° 3:1 hybrid composite is seen. From Figure 8 it is seen that the moisture absorption levels are again comparable at 500 Hours (0.5%) and 1000 hours (9.0%) to those attained previously.

Within the limits of this experiment it is almost certain that there is no effect of moisture on the following laminates for moisture saturation levels up to 1%.

Laminate	Ref. Fig.
Quasi/Graphite	12
Quasi/Hybrid 1:1	15
Transv./Hybrid 2:1	17
Quasi/Hybrid 8:1	20



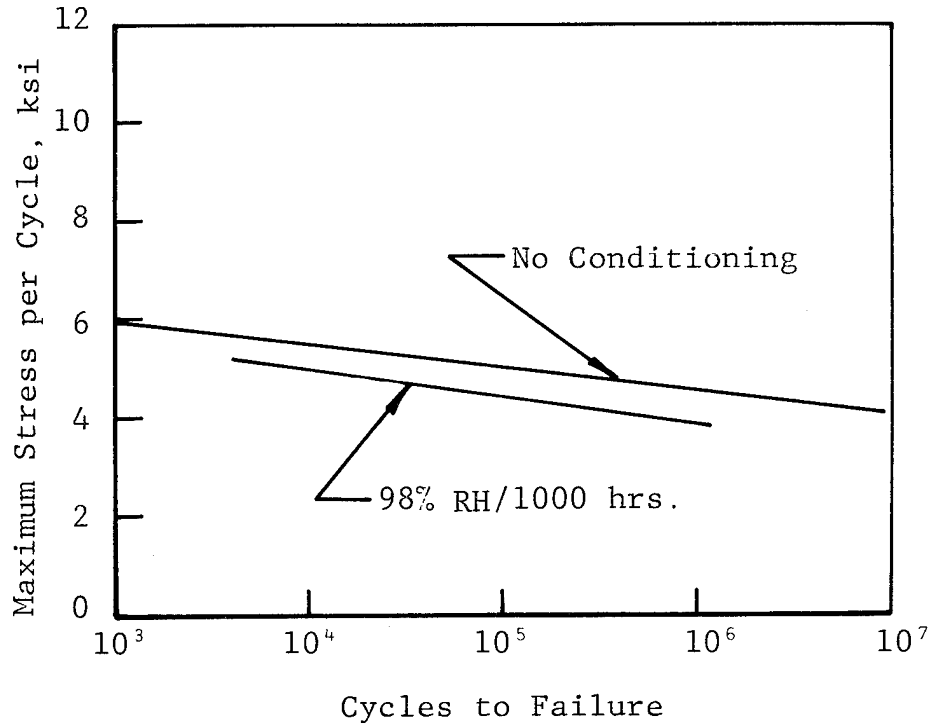
Orientation: $[0^{\circ}R/0^{\circ}L/0^{\circ}R/0^{\circ}L_2/0^{\circ}R/0^{\circ}L/0^{\circ}R]$

Temperature: $70^{\circ}F$

Stress Cycle: $R=0.1/T=70^{\circ}F/\phi=30$ Hertz

Percentage Graphite: 50%, by plies

Figure 13 Comparative Fatigue S-N Behavior for S-Glass/ T-300 Graphite/Narmco 5208 Hybrid Composites after Exposure to Various Hostile Environments.



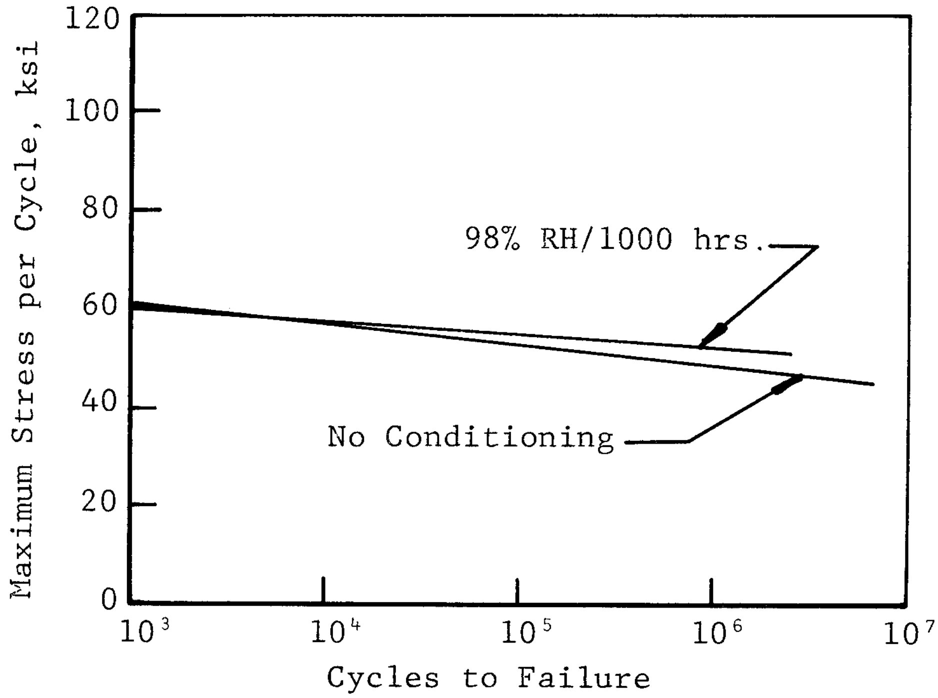
Orientation: [90°R/90°L/90°R/90°L/90°L/90°R/90°L/90°R]

Temperature: 70°F

Stress Cycle: R=0.1/T=70°F/ϕ=30 Hertz

Percentage Graphite: 50%, by plies

Figure 14 Comparative Fatigue S-N Behavior for S-Glass/ T-300 Graphite/Narmco 5208 Hybrid Composites after Exposure to Various Hostile Environments.



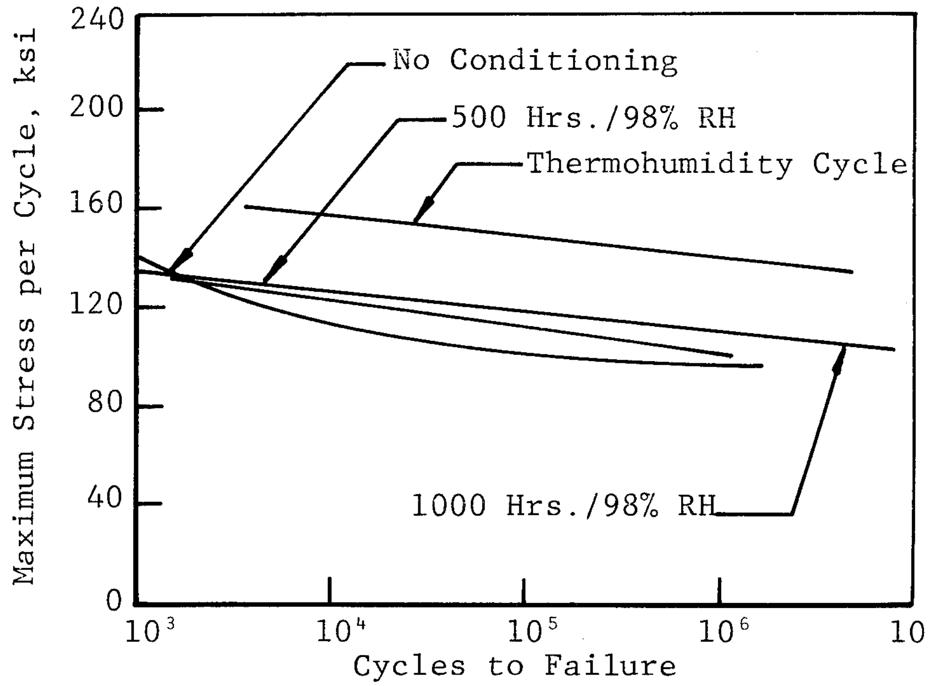
Orientation: $[0^{\circ}R/\pm45^{\circ}L/90^{\circ}R_2/\pm45^{\circ}L/0^{\circ}R]$

Temperature: $70^{\circ}F$

Stress Cycle: $R=0.1/T=70^{\circ}F/\phi=30$ Hertz

Percentage Graphite: 50%, by plies

Figure 15 Comparative Fatigue S-N Behavior for S-Glass/ T-300 Graphite/Narmco 5208 Hybrid Composites After Exposure to Various Hostile Environments.



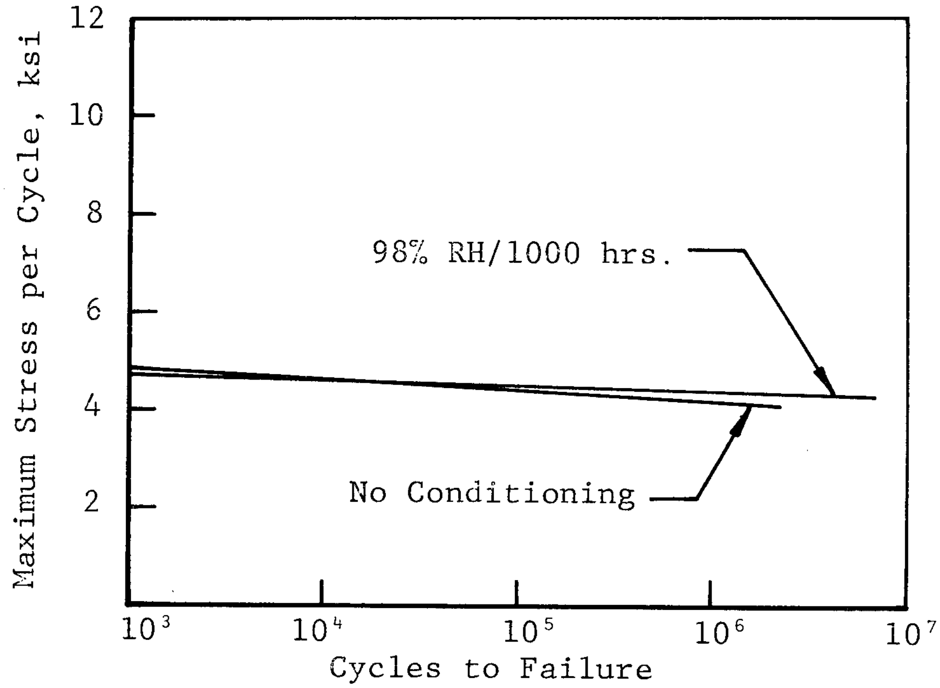
Orientation: $[0^{\circ}R/0^{\circ}L/0^{\circ}R_2/0^{\circ}L/0^{\circ}R]$

Temperature: $70^{\circ}F$

Stress Cycle: $R=0.1/T=70^{\circ}F/\phi=30$ Hertz

Percentage Graphite: 67%, by plies

Figure 16 Comparative Fatigue S-N Behavior for S-Glass/T-300 Graphite/Narmco 5208 Hybrid Composites after Exposure to Various Hostile Environments.



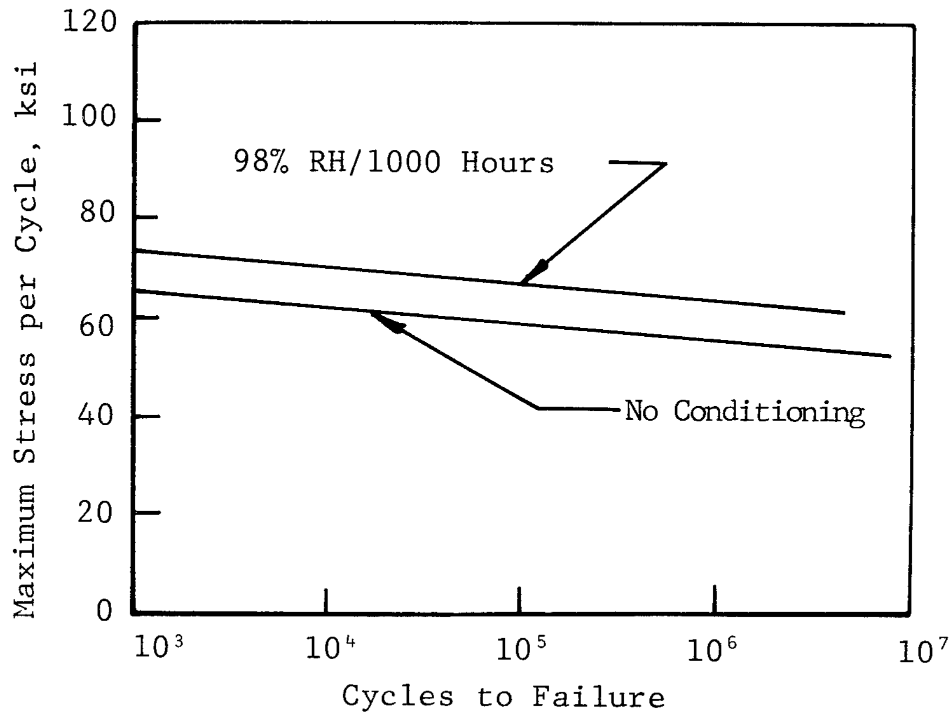
Orientation: $[90^{\circ}R/90^{\circ}L/90^{\circ}R_2/90^{\circ}L/90^{\circ}R_2/90^{\circ}L/90^{\circ}R]$

Temperature: $70^{\circ}F$

Stress Cycle: $R=0.1/T=70^{\circ}F/\phi=30$ Hertz

Percentage Graphite: 67%, by plies

Figure 17 Comparative Fatigue S-N Behavior for S-Glass/T-300 Graphite/Narmco 5208 Hybrid Composites after Exposure to Various Hostile Environments.



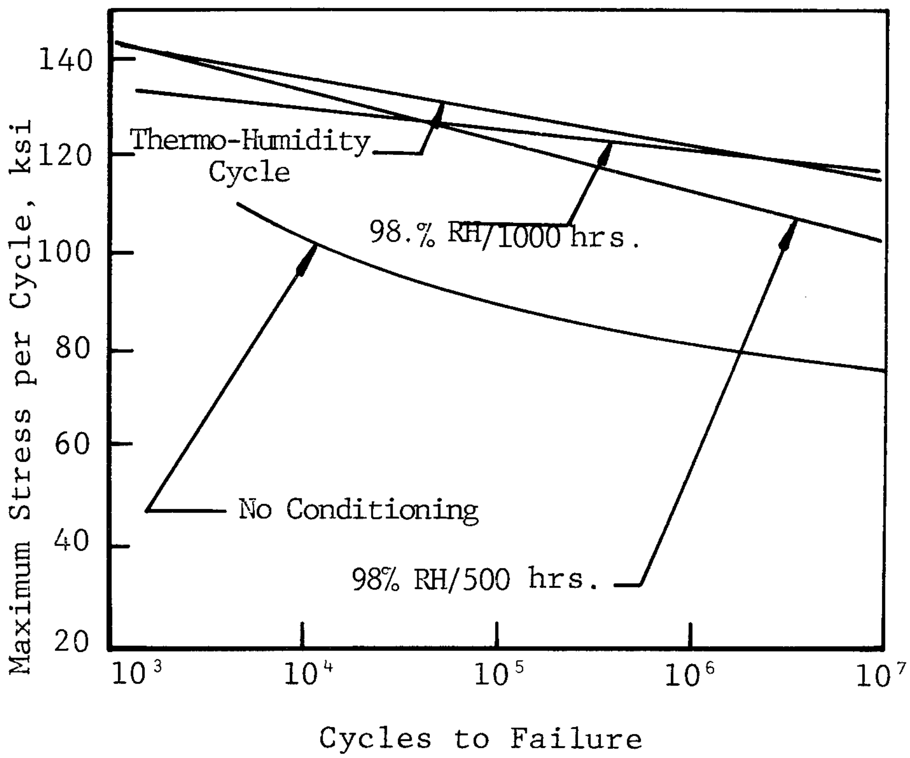
Orientation: $[0^\circ R/90^\circ R/\pm45^\circ L/90^\circ R/0^\circ R_2/90^\circ R/\mp45^\circ L/90^\circ R/0^\circ R]$

Temperature: $70^\circ F$

Stress Cycle: R=0.1/T=70°F/ϕ=30 Hertz

Percentage Graphite: 67%, by plies

Figure 18 Comparative Fatigue S-N Behavior for S-Glass/ T-300 Graphite/Narmco 5208 Hybrid Composites After Exposure to Various Hostile Environments.



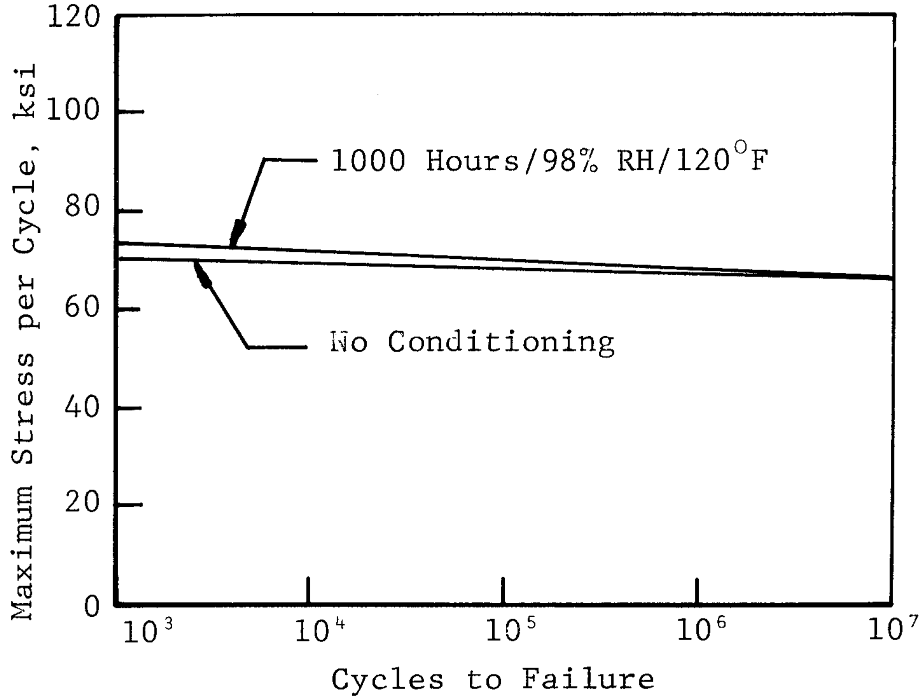
Orientation: $[0^{\circ}R/0^{\circ}L/0^{\circ}R_4/0^{\circ}L/0^{\circ}R]$

Temperature: $70^{\circ}F$

Stress Cycle: $R=0.1/T=70^{\circ}F/\phi=30$ Hertz

Percentage Graphite: 75%, by plies

Figure 19 Comparative Fatigue S-N Behavior for S-Glass/T-300 Graphite/Narmco 5208 Hybrid Composites after Exposure to Various Hostile Environments.



Orientation: $[0^{\circ}R/90^{\circ}R/0^{\circ}R/90^{\circ}R/\pm45^{\circ}L/90^{\circ}R/$
$0^{\circ}R_2/90^{\circ}R/\mp45^{\circ}L/90^{\circ}R/0^{\circ}R/90^{\circ}R/0^{\circ}R]$

Temperature: $70^{\circ}F$

Stress Cycle: $R=0.1/T=70^{\circ}F/\phi=30$ Hertz

Percentage Graphite: 75%, by plies

Figure 20 Comparative Fatigue S-N Behavior for S-Glass/T-300 Graphite/Narmco 5208 Hybrid Composites after Exposure to Various Hostile Environments.

This then leaves the question as to how the other laminates are effected. We might add to the above list the 90° Glass as well except for the 1000 hour exposure to 98% RH which showed considerable degradation (Figure 10). The most confusing results are then those for the thermo-humidity cycles. A summary of the overall effects of the thermo hymidity exposure are as follows:

Laminate	Effect	Reference Fig.
0° -Glass	Increase	9
90° -Glass	Decrease	10
Quasi-Glass	Increase	11
Quasi-Graph	none	12
0°-Hybrid 1:1	Increase	13
0°-Hybrid 2:1	Increase	16
0°-Hybrid 3:1	Increase	19
0° Graphite	Increase	(Ref. 1)
$(0^{\circ}/90^{\circ}/\pm45^{\circ})$ Graphite	None	(Ref. 2)

Thus it can be seen that all 0° composites either basic or hybrid increase in fatigue resistance after the thermo-humidity conditioning, the 90° composite decreased and the quasi-(or near quasi-) isotropic laminates show either no effect or a slight increase. It appears that the matrix is severely damaged by the thermo-humidity cycle and the 0° composites then act as parallel bundles of fibers able to sustain load and resisting crack propagation across the separate bundles. However the principal strengths of the 90° composites lie in the matrix, which, when damaged by the thermo-humidity cycling, is unable to sustain the repeated load cycling, as in the non-exposed state. The mixed effect on the 0° and 90° composites then shows up in the quasi-isotropic laminates producing either no effect or a slight increase in fatigue resistance. This occurs since the principal load-sustaining plies are the 0° plies.

In order to examine how hybridization affects the fatigue resistance of the composites, all the data for a given orientation was plotted on a common chart. The prior conditioning was held constant for this purpose. Figure 21 shows the 0° composites both basic and hybrids plotted simultaneously. The unconditioned and those exposed for 1000 hours to 98% RH and $120^{\circ}F$ are shown separately in Figure 21a and Figure 21b respectively. No curves are shown superposed over the individual data points to assist in clarifying the trends.

Note from Figure 21a that the 0° glass/epoxy composite behaves in the classical manner decreasing in a curved fashion as the cycles increase. The 0° graphite/epoxy composite also behaves in its classical fashion with a very flat response to stress cycling over the entire range from 1000 to 5,000,000 cycles.

The hybrid 0° composites show a mixed behavior with the best performance shown by 2:1 Graphite to Glass ratio. In Reference 11 this behavior was also seen, i.e., the 2:1 performance was always better than 1:1 or 3:1 performance and almost always nearly as good as the pure graphite/epoxy performance. The reason for this is probably the good stacking sequencing of the graphite and glass in the laminate with a rather uniform distribution of glass and graphite plies thus producing a minimum of shear transfer problems at the interfaces of the glass and graphite plies.

Similar behavior is shown in Figure 21b which shows the undirectional laminate fatigue behavior after conditioning at 98% RH for 1000 hours. The 0° glass/epoxy behavior shows some moisture degradation but the graphite/epoxy and glass/graphite epoxy hybrid composites show very little fatigue degradation. It is also interesting to observe that the spread of the data at every given cyclic life level when compared with the unexposed material. Again the 2:1 hybrids show better fatigue performance than do the 1:1 or 3:1 hybrid composites.

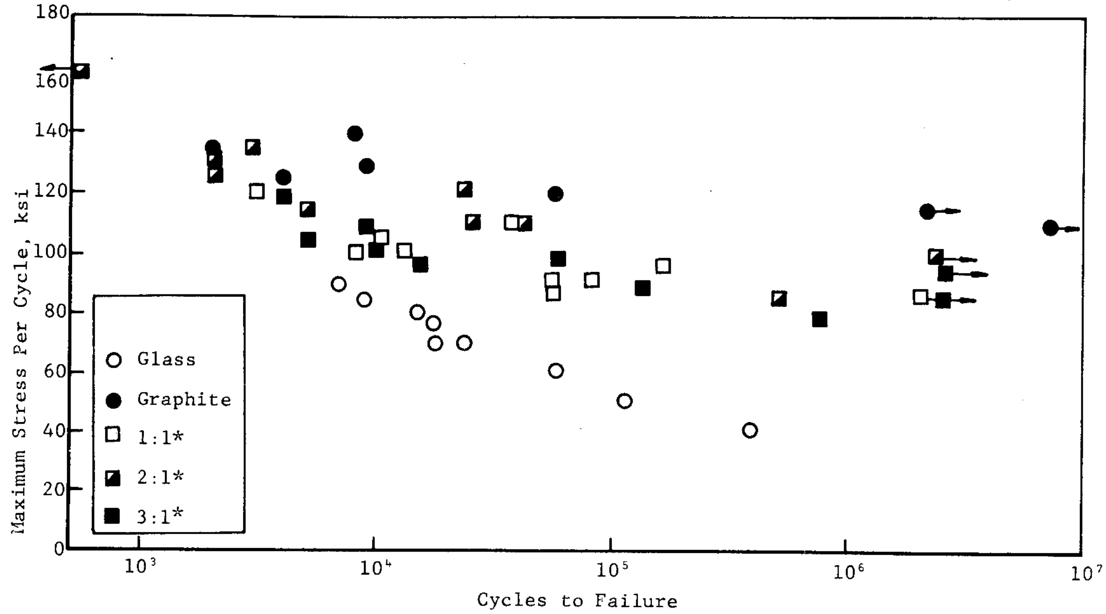


Figure 21a Comparison of the Fatigue S-N Behavior of Unidirectional T300 Graphite/S-Glass/Narmco 5208 Hybrid Composites
*Ratio of Graphite to Glass

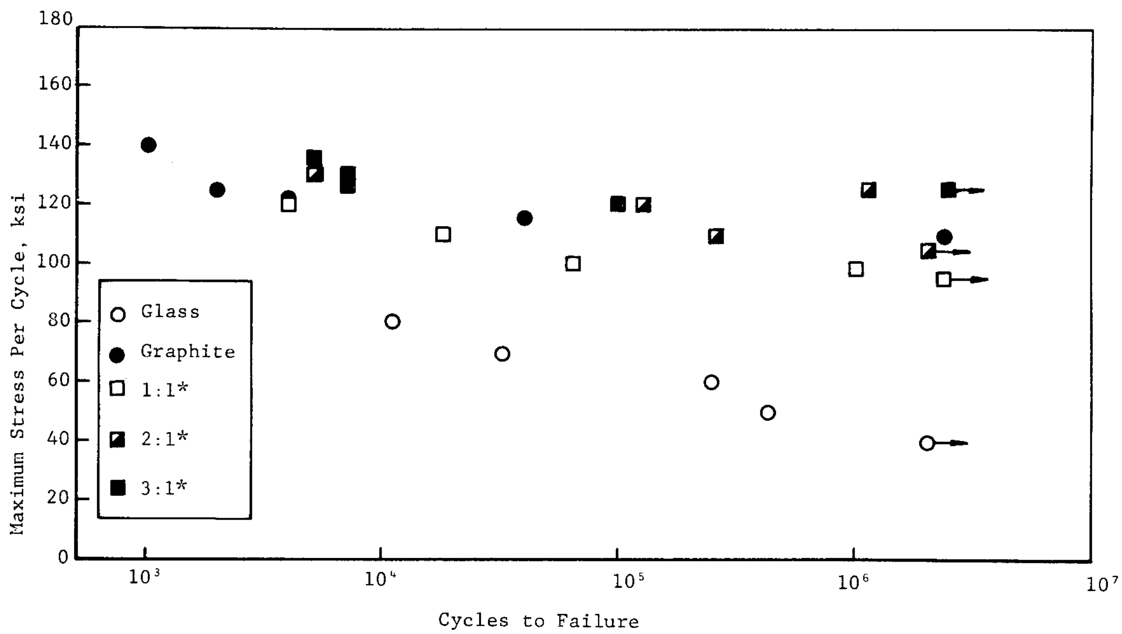


Figure 21b Comparison of the Fatigue S-N Behavior of Unidirectional T300 Graphite/S-Glass/Narmco 5208 Hybrid Composites after Conditioning at 98% RH and 120°F for 1000 Hours.
*Ratio of Graphite to Glass

The quasi-isotropic hybrid behaviors are even more remarkable with considerably better fatigue performance for the hybrids than for the basic laminates themselves. This is true for both unconditional laminates and laminates with 1000 hour exposure to 98% RH and 120^{o}F. The glass by itself degrades rapidly with mechanical stress cycling but when used in conjunction with the graphite apparently improves the already good graphite fatigue performance.

The static mechanical properties of the hybrid composite materials after fatigue cycling (residual properties) are shown in Figures 23-34. Figure 23 for the 0^{o} S-Glass material typifies the general behavior of the residual mechanical properties after fatigue cycling. The strength decreases slightly as a function of stress cycles, the elastic modulus is virtually constant and the residual Poisson's ratio (lateral strain to longitudinal strain) increases slightly. This behavior has a sound mechanistic basis. The strength depends to some degree on the integrity of the fiber to matrix bond which is gradually broken up as a function of load cycles and thus decreases. The elastic modulus is principally a measure of the stiffness of the glass filaments which should be unaffected by stress cycles. In fact in a 65 Volume percent composite 97% of the composite modulus is contributed by the glass and 3% by the matrix according to a rule-of-mixtures. Finally, as the matrix begins to decouple from the fibers, the Poisson's Ratio should increase because the transverse strains should increase. In an all 0^{o} composite either single fiber phase or hybrid, this effect should be accentuated by the lack of transverse fibers to resist the lateral deformations.

Only in one isolated case, the quasi-isotropic glass/epoxy composite did the elastic modulus show a significant decrease at the multi-million stress cycle exposure level and this single specimen should not be taken out of context of the overall trends for the entire test program.

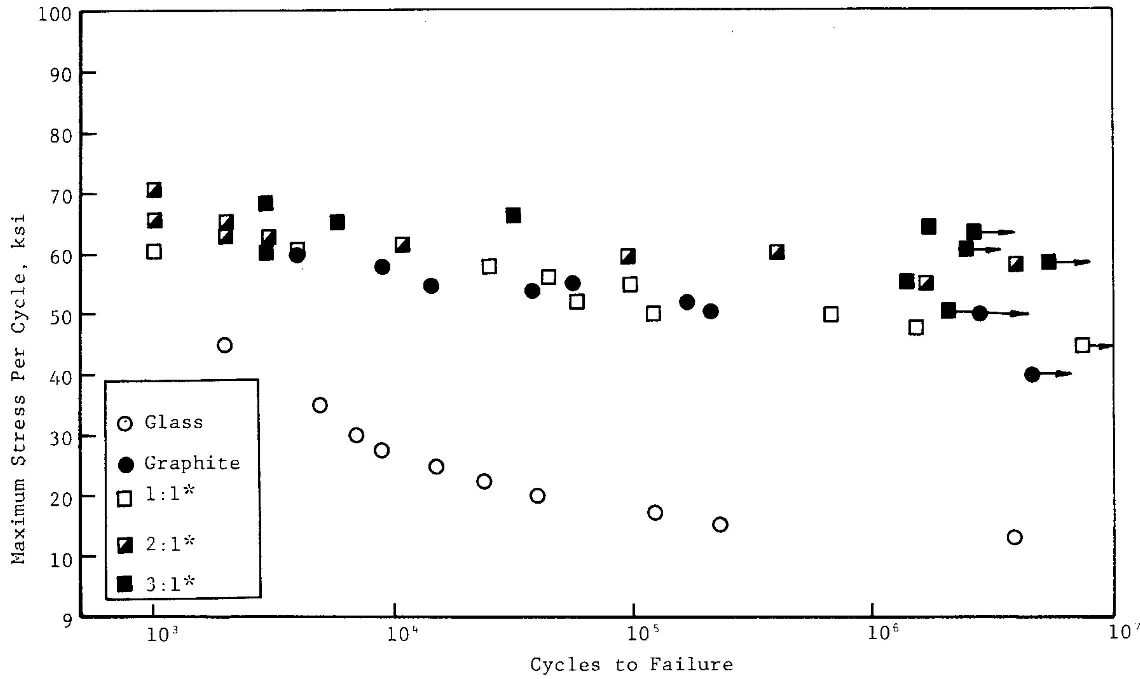


Figure 22a Comparison of the Fatigue S-N Behavior of Quasi-Isotropic T-300 Graphite/S-Glass/Narmco 5208 Hybrid Composites.
*Ratio of Graphite to Glass

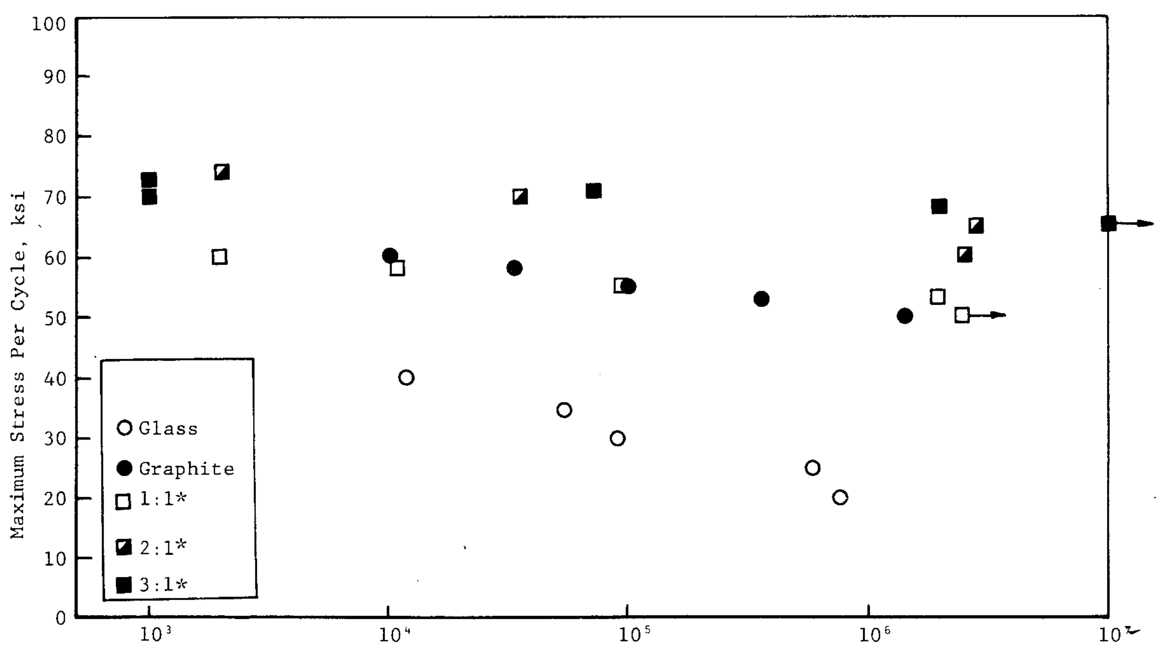
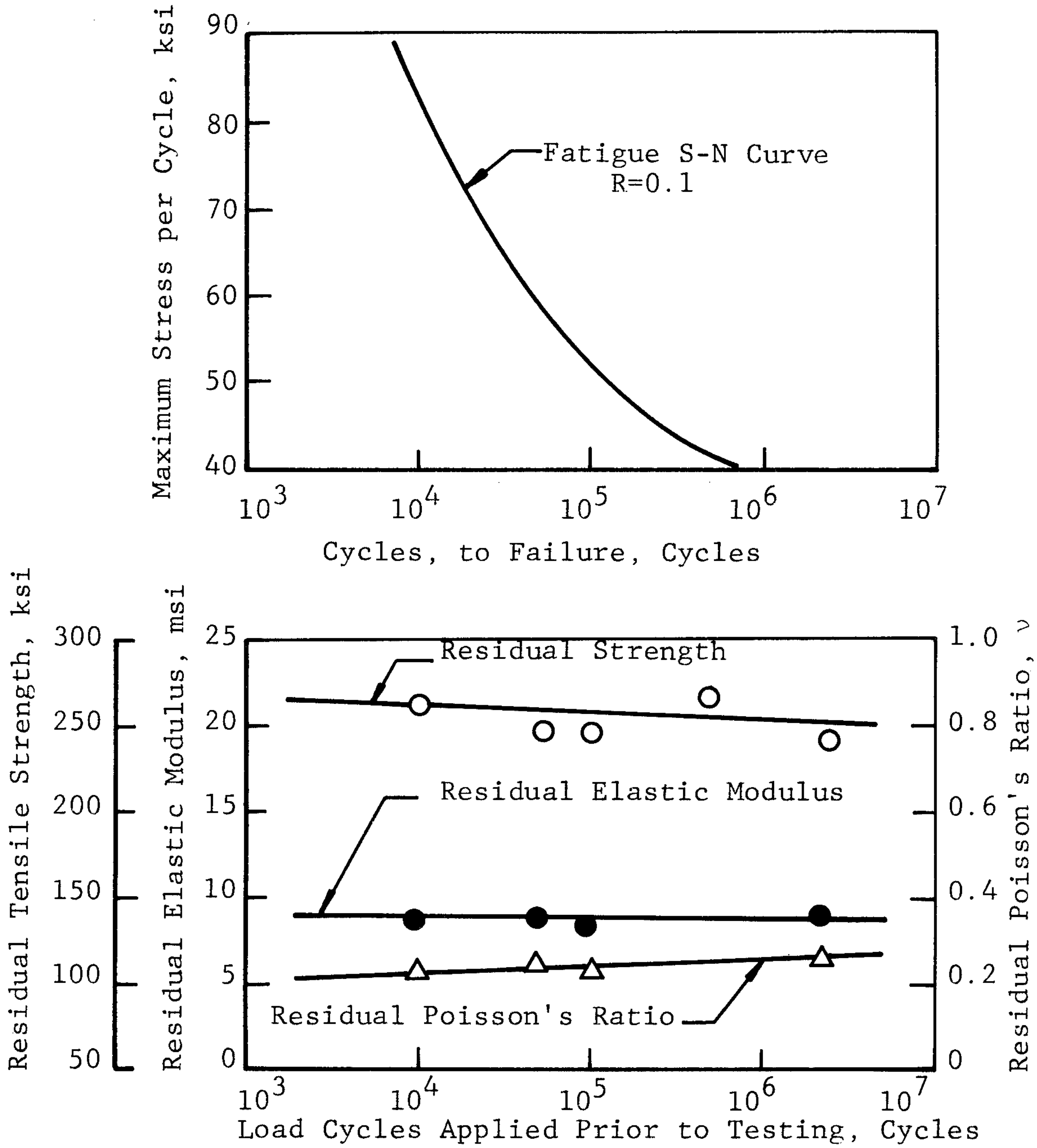


Figure 22b Comparison of the Fatigue S-N Behavior of Quasi-Isotropic T300/Graphite/S-Glass/Narmco 5208 Hybrid Composites after Conditioning at 98% RH and 120°F for 1000 hours.
*Ratio of Graphite to Glass

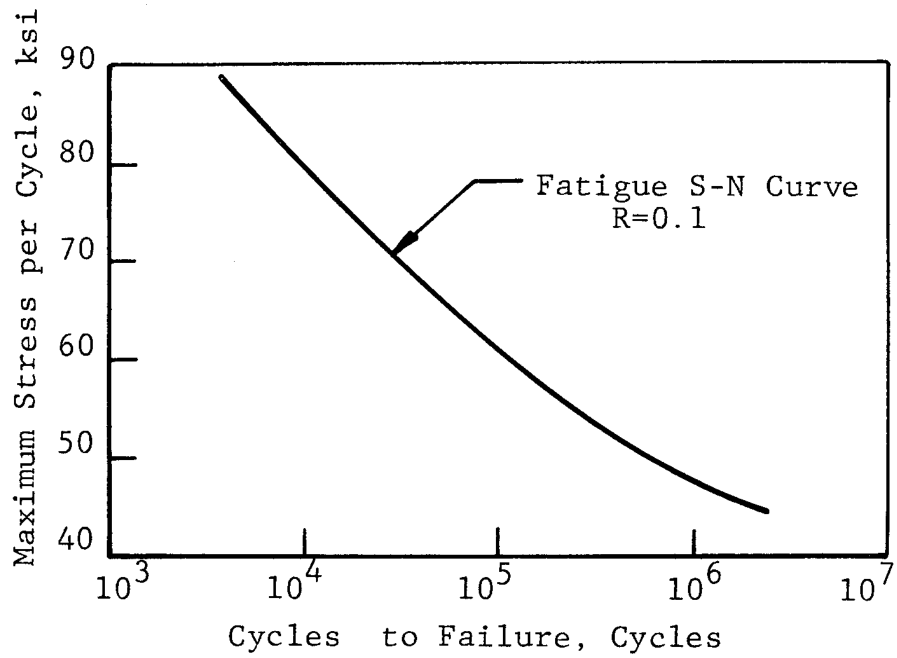


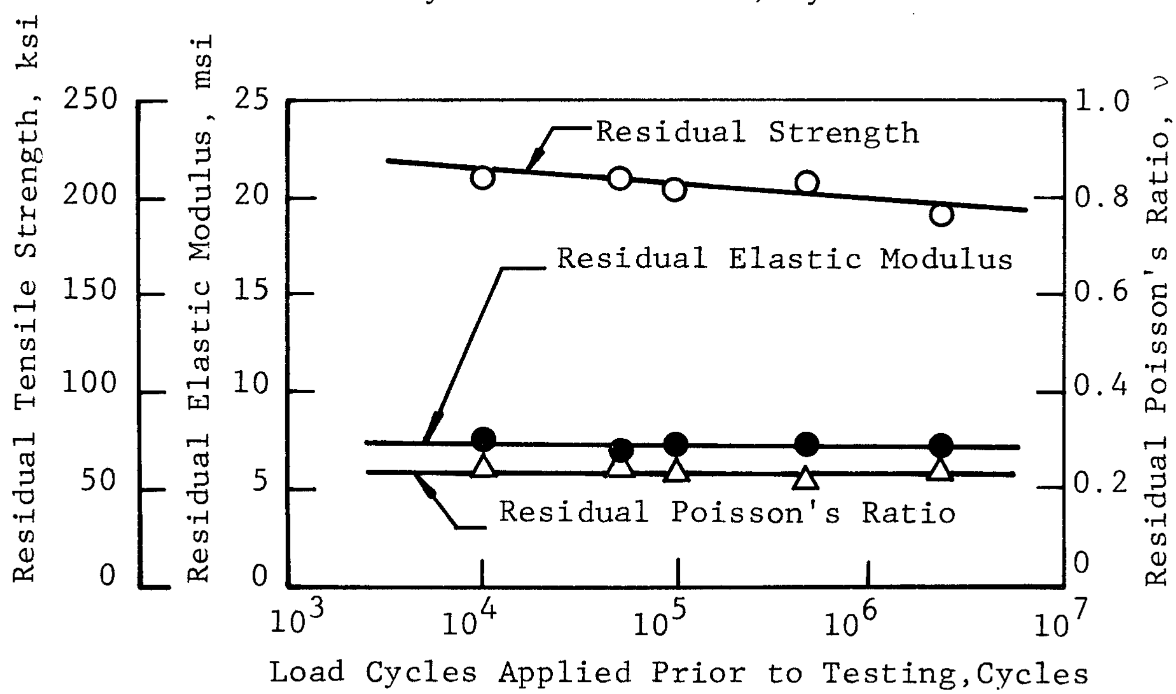
Material: $[0°L_6]$

Cyclic Stress Level: 30 ksi

Prior Conditioning : None

Figure 23 Residual Strength Elastic Modulus and Poisson's Ratio for Composite Material (ϕ=1800 cpm, R=0.1, T=70°F, orientation, stress level and prior conditioning as noted), 0% Graphite by plies.



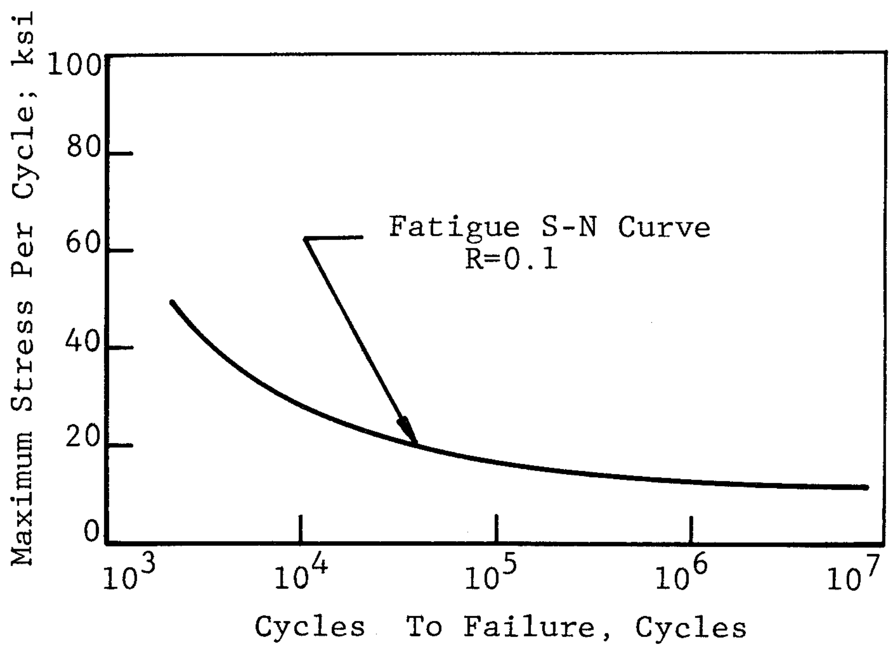


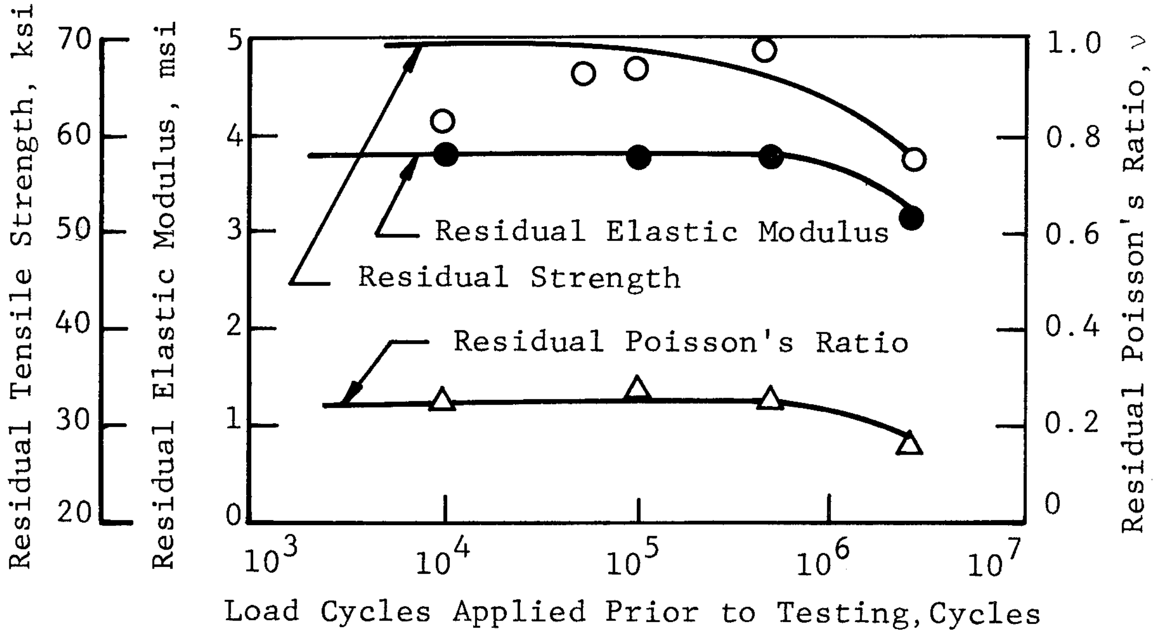
Material: $[0°L_6]$

Cyclic Stress Level: 30 ksi

Prior Conditioning : 98% RH/120°F/1000 Hours

Figure 24 Residual Strength, Elastic Modulus and Poisson's Ratio for Composite Material (ϕ=1800 cpm, R=0.1, T=70°F, orientation, stress level and prior conditioning as noted), 0% Graphite, by plies.



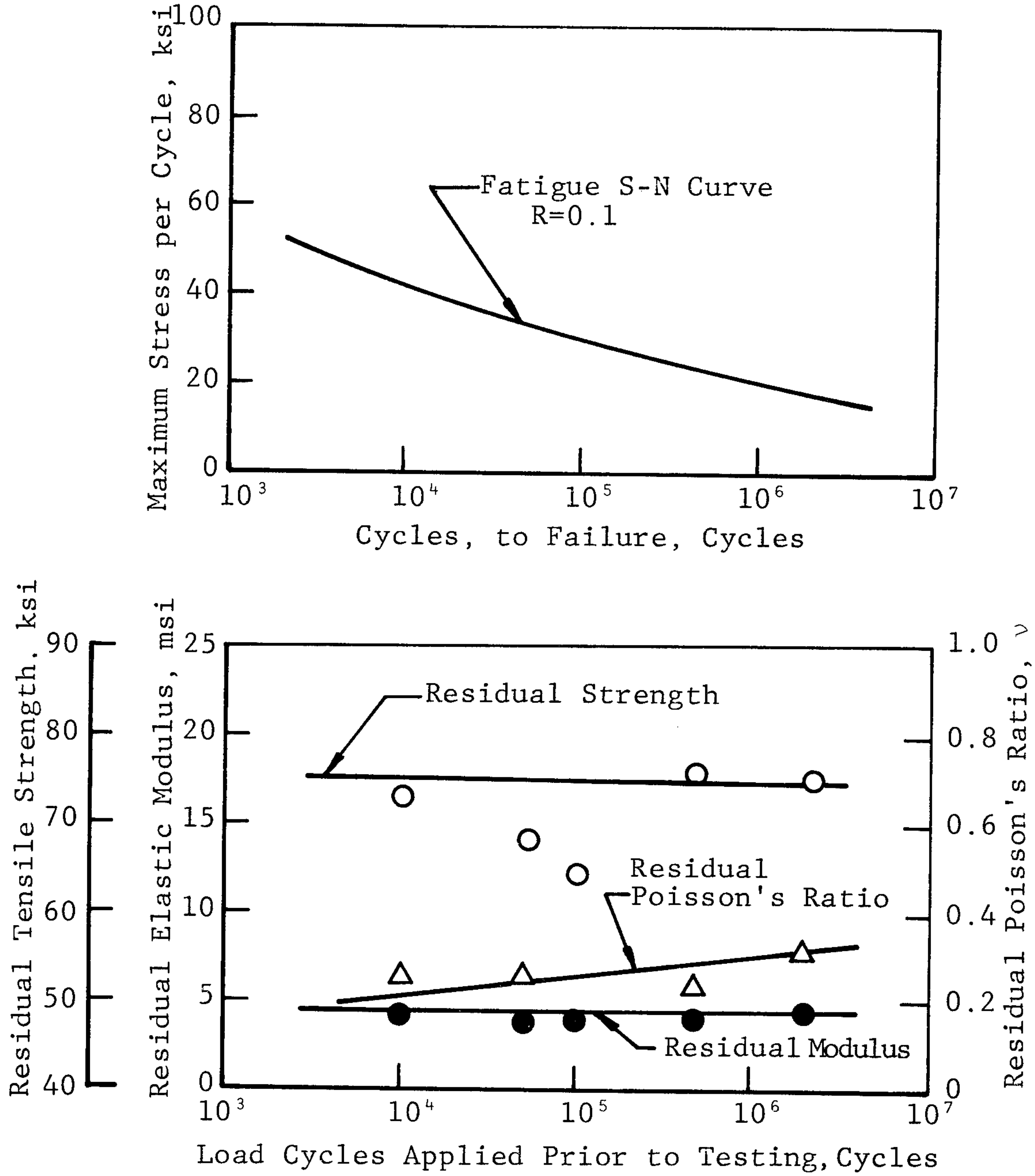


Material: $[0°L/\pm45°L/90°L_2/\mp45°L/0°L]$

Cyclic Stress Level: 13

Prior Conditioning: None

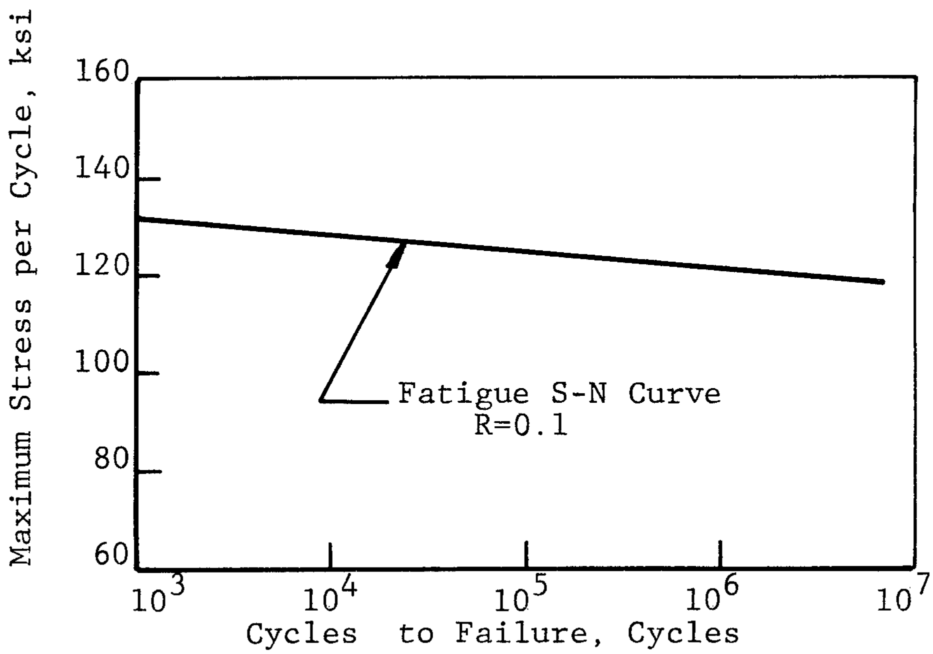
Figure 25 Residual Strength, Elastic Modulus and Poisson's Ratio for Composite Material (ϕ=1800 cpm, R=0.1, T=70°F, orientation, stress level and prior conditioning as noted), 0% Graphite, by plies.

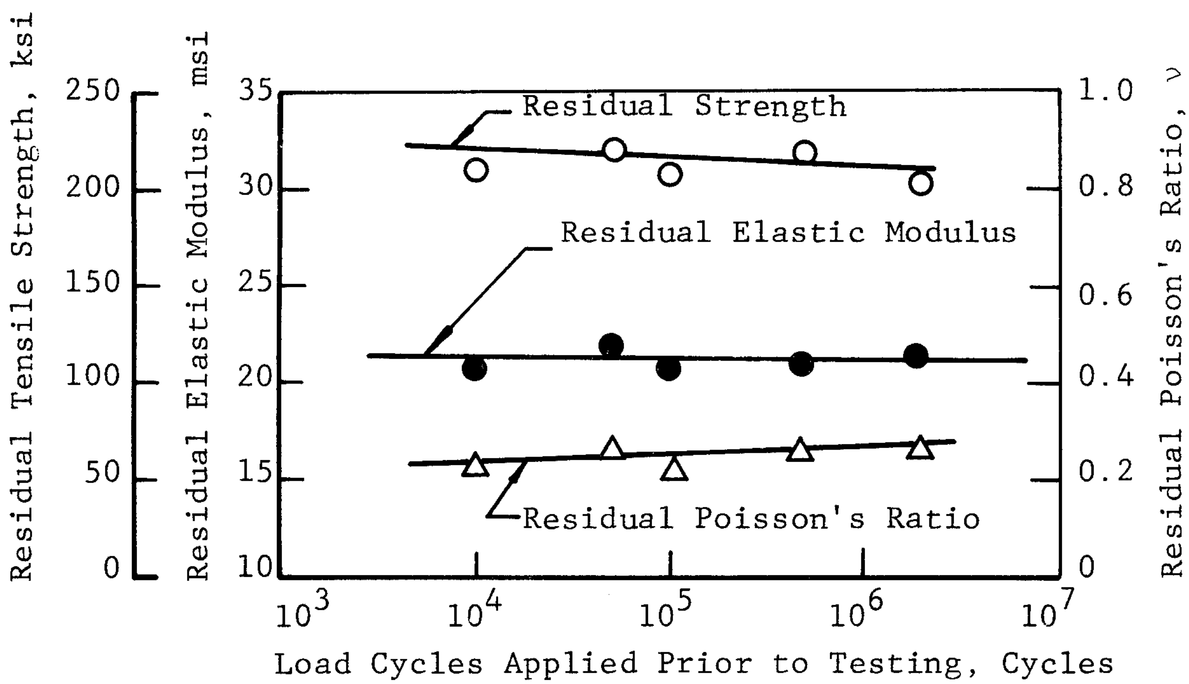


Material: $[0^{\circ}L/\pm45^{\circ}L/90^{\circ}L_2/\mp45^{\circ}L/0^{\circ}L]$

Cyclic Stress Level: 13
Prior Conditioning: 98% RH/120°F/1000 Hours

Figure 26 Residual Strength, Elastic Modulus and Poisson's Ratio for Composit Material (ϕ=1800 cpm, R=0.1, T=70°F, orientation, stress level and prior conditioning as noted.), 0% Graphite, by plies.



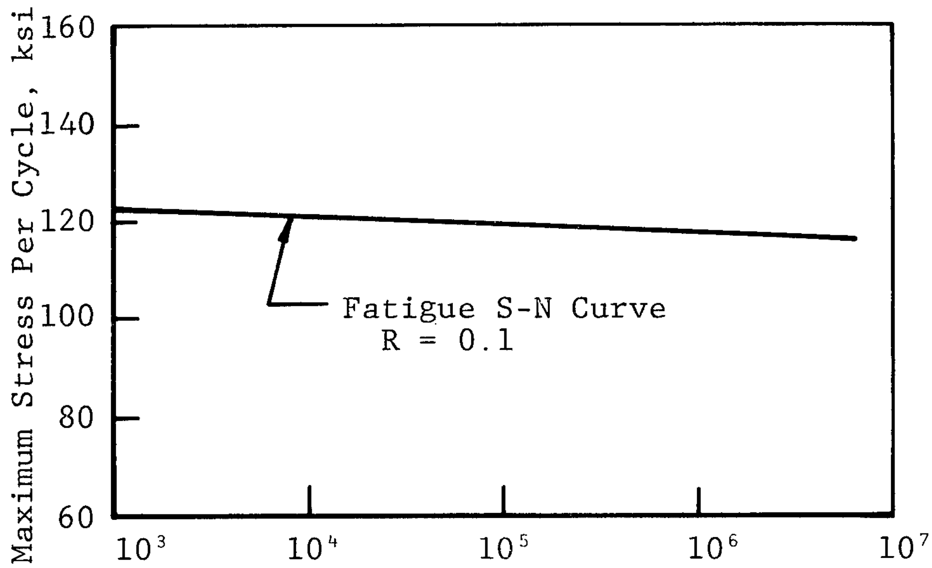


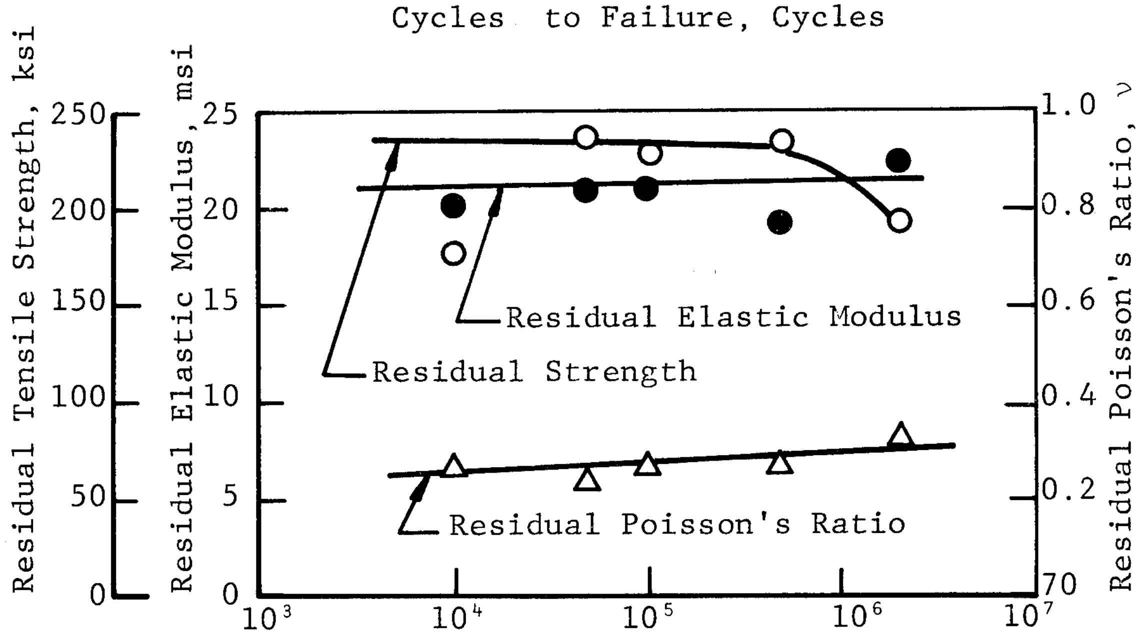
Material: $[0°R_6]$

Cyclic Stress Level: 122 ksi

Prior Conditioning : None

Figure 27 Residual Strength, Elastic Modulus and Poisson's Ratio for Composite Material (ϕ=1800 cpm, R=0.1, T=70°F, orientation, stress level and prior conditioning as noted), 100% Graphite, by plies.

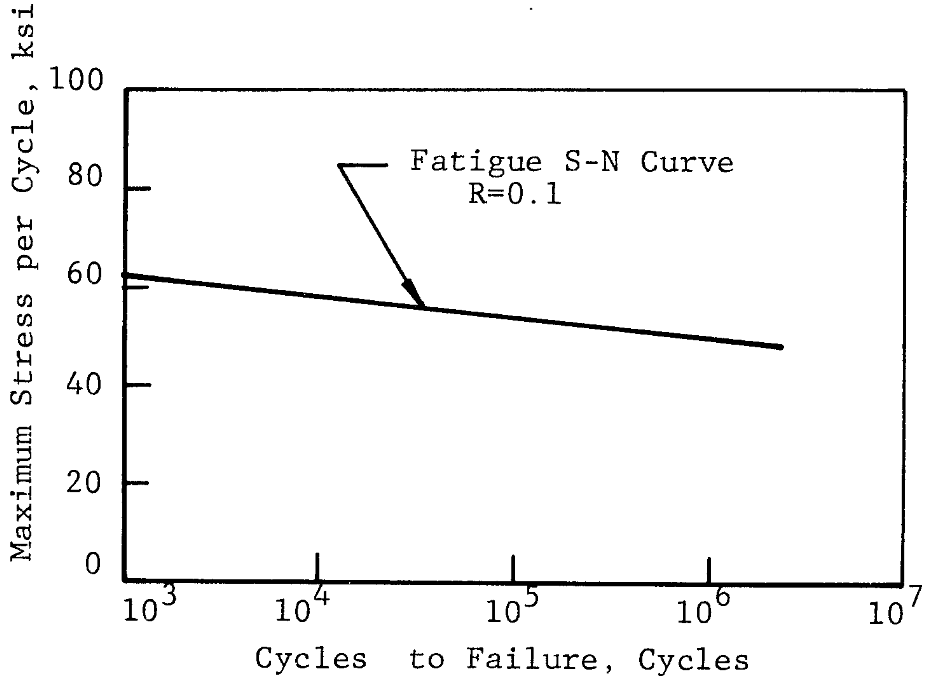


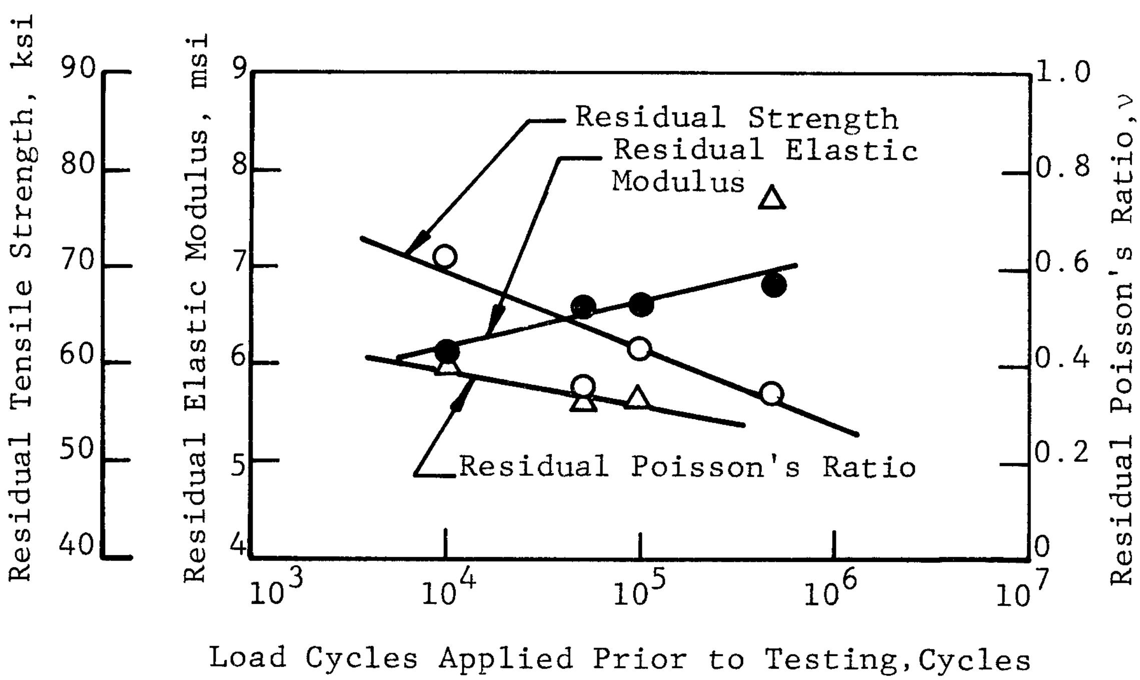


Material: $[0^{O}R_6]$

Cyclic Stress Level: 122 ksi
Prior Conditioning: 98% RH/120°F/1000 Hours

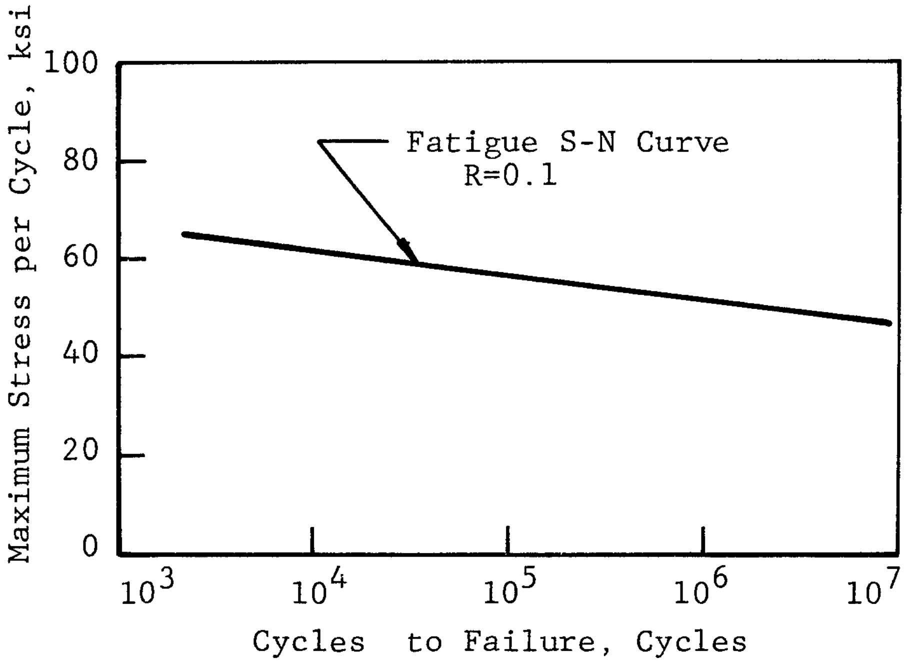
Figure 28 Residual Strength, Elastic Modules and Poisson's Ratio for Composite Material (ϕ=1800 cpm, R=0.1, T=70°F, orientation, stress level and prior conditioning as noted.), 100% Graphite, by plies.

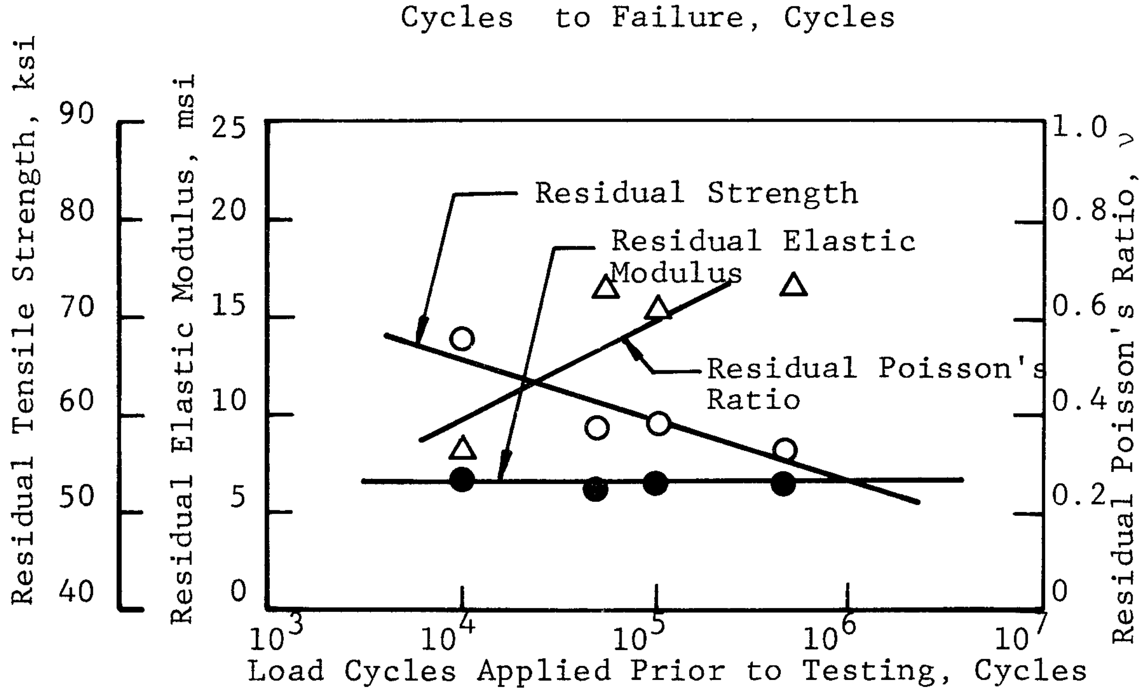




Material:	$[0°R/\pm45°R/90°R_2/\mp45°R/0°R]$
Cyclic Stress Level:	50 ksi
Prior Conditioning:	None

Figure 29 Residual Strength, Elastic Modulus and Poisson's Ratio for Composite Material (ϕ=1800 cpm, R=0.1, T=70°F, orientation, stress level and prior conditioning as noted), 100% Graphite, by plies.



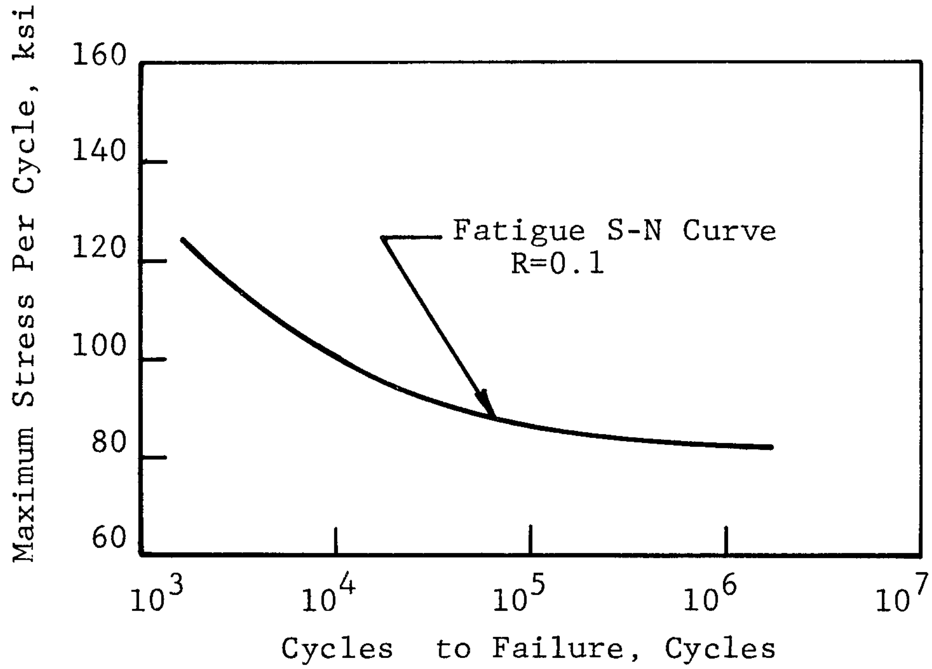


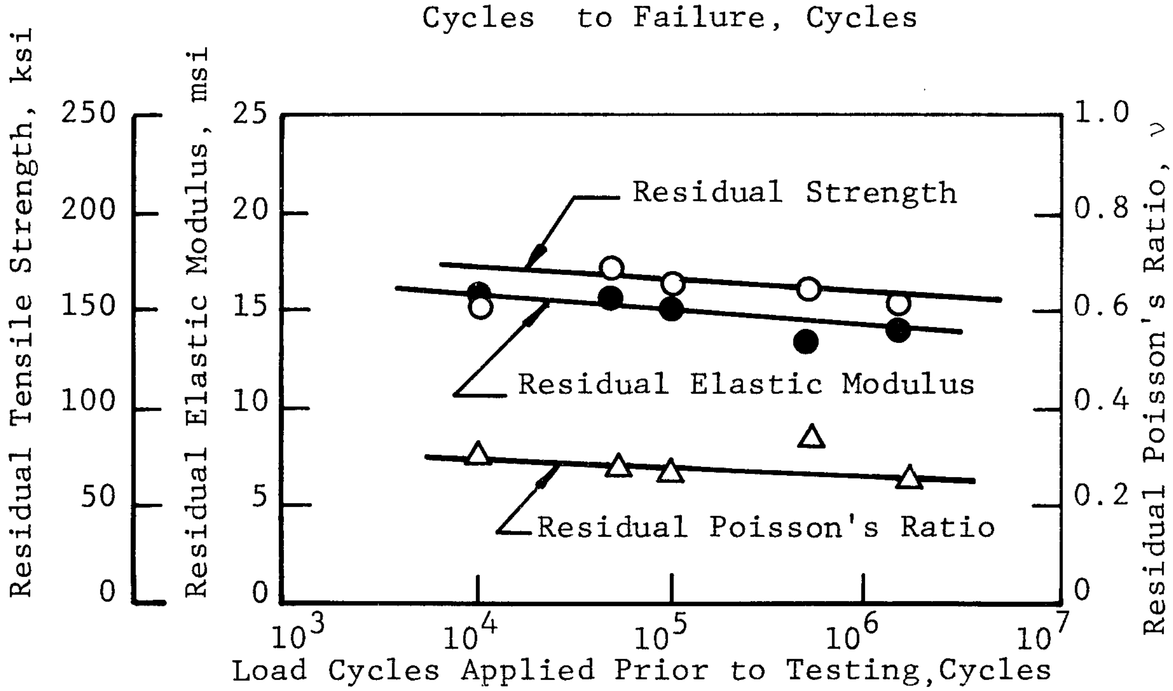
Material: $[0°R/\pm45R/90°R_2/\mp45°R/0°R]$

Cyclic Stress Level: 50 ksi

Prior Conditioning : 98% RH/120°F/1000 Hours

Figure 30 Residual Strength, Elastic Modulus and Poisson's Ratio for Composite Material (ϕ=1800 cpm, R=0.1, T=70°F, orientation, stress level and prior conditioning as noted), 100% Graphite, by plies.



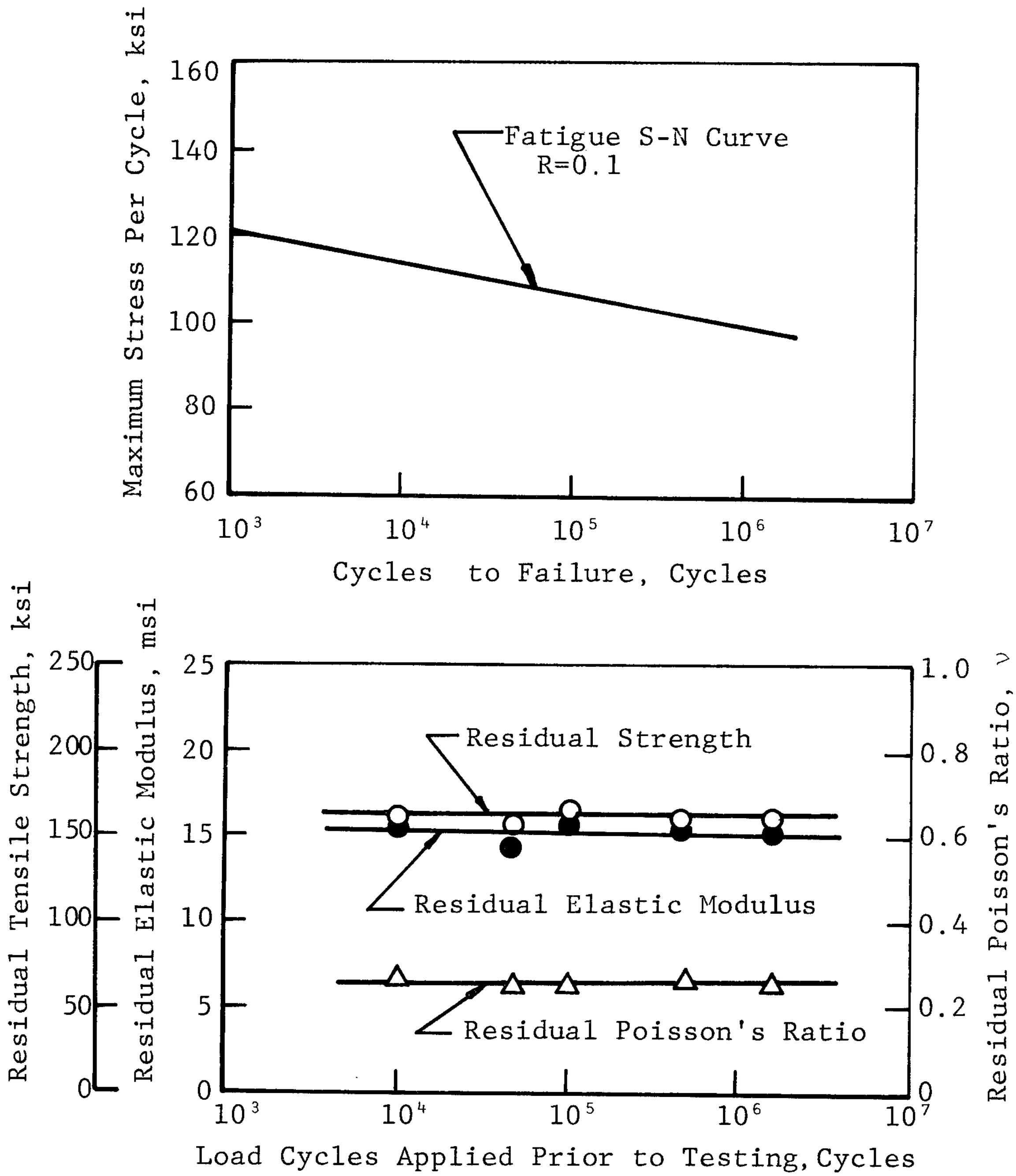


Material: $[0°R/0°L/0°R/0°L_2/0°R/0°L/0°R]$

Cyclic Stress Level: 85 ksi

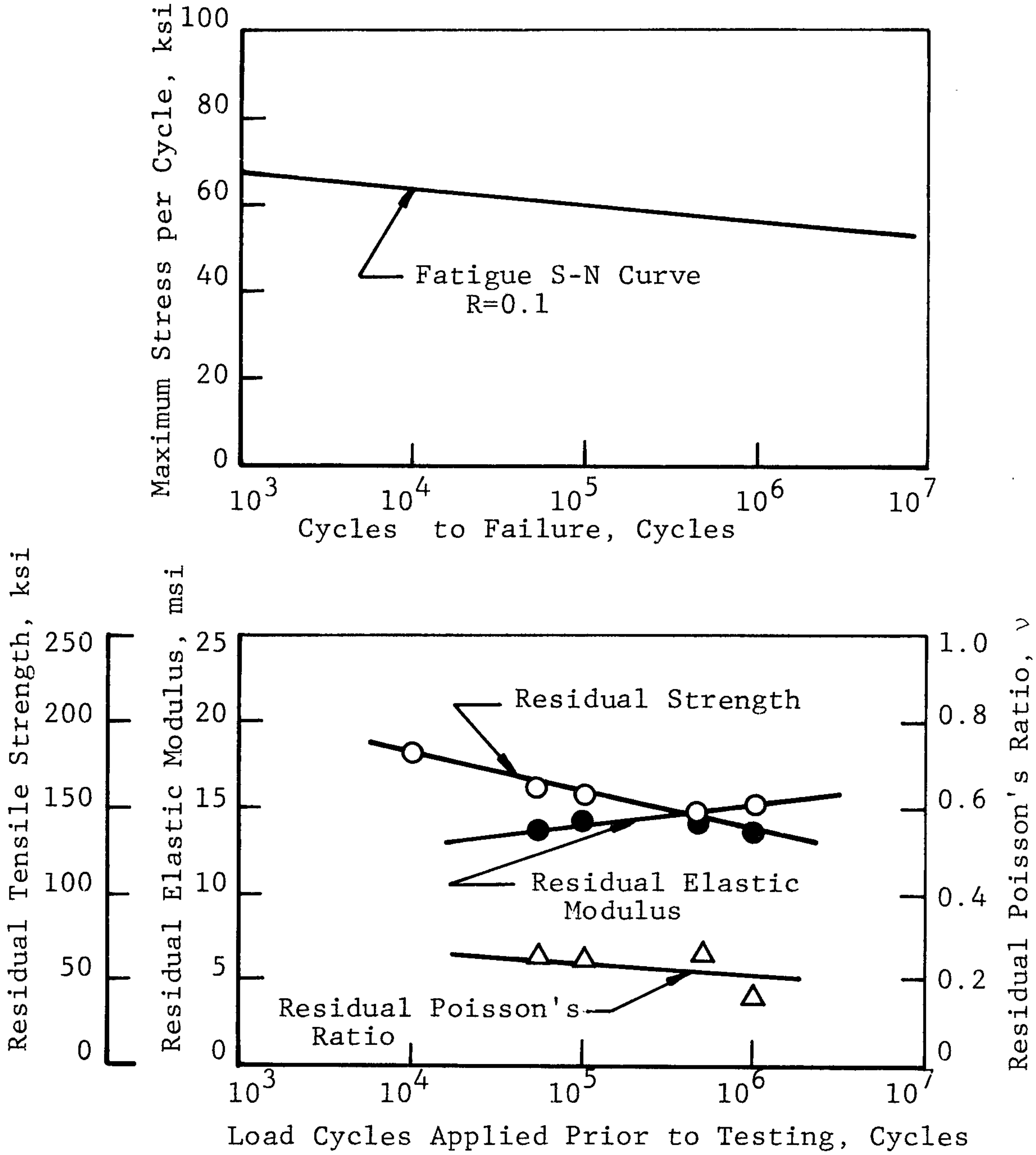
Prior Conditioning: None

Figure 31 Residual Strength, Elastic Modulus and Poisson's Ratio for Composite Material (ϕ=1800 cpm, R=0.1, T=70°F, orientation, stress level and prior conditioning as noted), 50% Graphite, by plies.



Material: $[0^{o}R/0^{o}L/0^{o}R/0^{o}L_2/0^{o}R/0^{o}L/0^{o}R]$
Cyclic Stress Level: 85 ksi
Prior Conditioning: 98% RH/120^{o}F/1000 Hours

Figure 32 Residual Strength, Elastic Modulus and Poisson's Ratio for Composite Material (ϕ=1800 cpm, R=0.1, T=70^{o}F, Orientation, Stress Level and Prior Conditioning as Noted.), 50% Graphite, by plies.

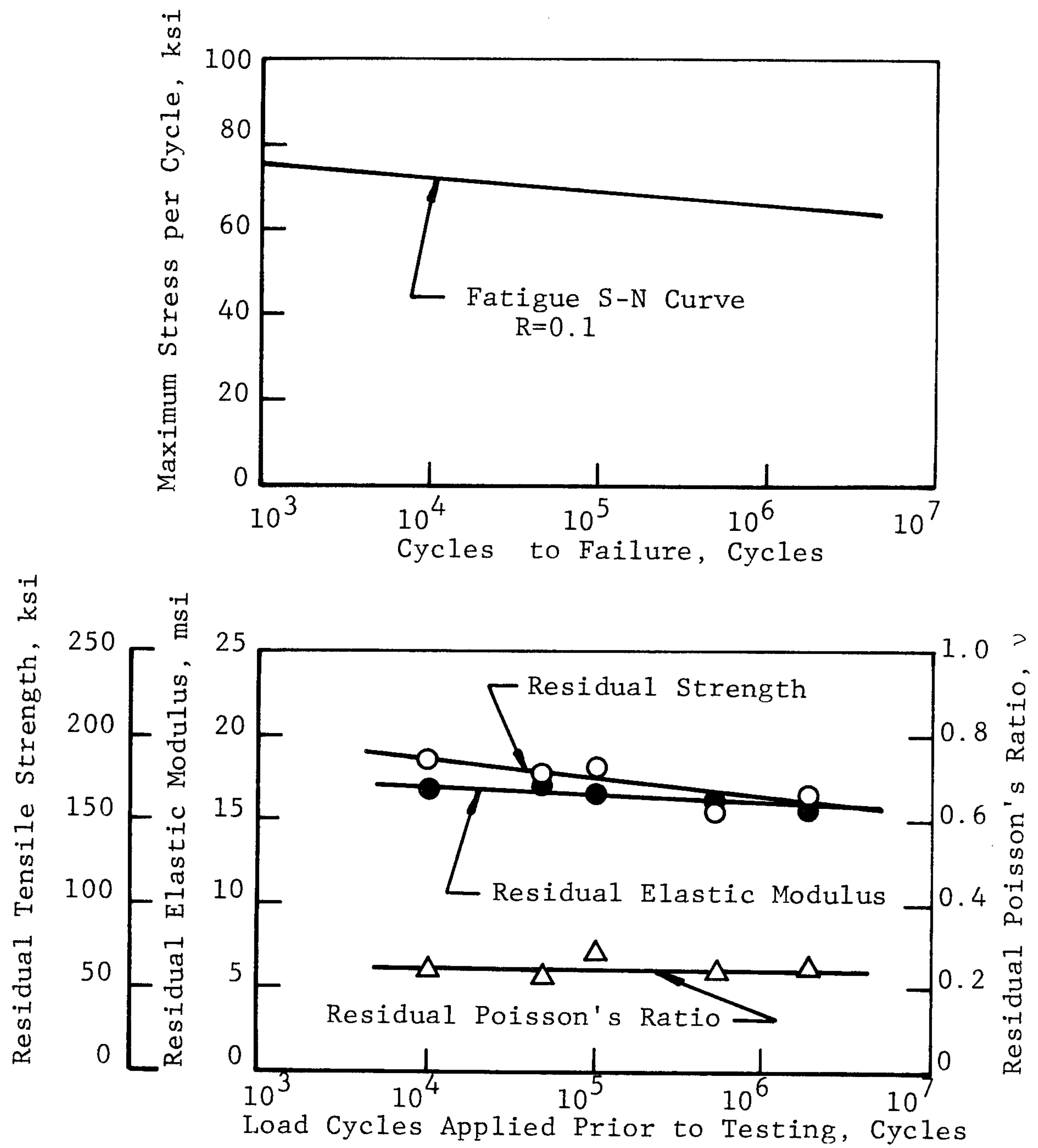


Material: $[0°R/90°R/\pm45°L/90°R/0°R_2/90°R/\mp45°L/90°R/0°R]$

Cyclic Stress Level: 100 ksi

Prior Conditioning : None

Figure 33 Residual Strength, Elastic Modulus and Poisson's Ratio for Composite Material (ϕ=1800 cpm, R=0.1, T=70°F, orientation, stress level and prior conditioning as noted), 67% graphite, by plies.



Material: [0°R/90°R/+45°L/90°R/0°R_2/90°R/ ∓45L/9$\overline{0}$°R/0°R]

Cyclic Stress Level: 100 ksi

Prior Conditioning : 98% RH/120°F/1000 Hours

Figure 34 Residual Strength, Elastic Modulus and Poisson's Ratio for Composite Material (ϕ=1800 cpm, R=0.1, T=70°F, orientation, stress level and prior conditioning as noted), 67% Graphite, by plies.

The overall results demonstrate rather conclusively that the composite moduli of the hybrids do not decrease as a function of stress cycling, at least in the range of 10^3 cycles to 10^7 cycles.

The only anomalous behavior was seen in the quasi-isotropic all graphite/epoxy composites where substantial loss in the residual strength was observed and an out-of-the-ordinary increase in Poisson's Ratio was observed for both the unconditioned and 98% RH/1000 hours exposure laminates. The stress cycling at 50 ksi or over 90% of the 10^7 cyclic life stress level may have been too high and indeed in each of the data sets at least one of the specimens broke prior to completion of the stress cycling preparatory to obtaining the residual properties.

SECTION V

5.0 IMPACT BEHAVIOR OF HYBRID COMPOSITES

Unnotched laminates of both the basic and hybrid composites were studied for their impact resistance in accordance with the test program shown earlier in Table II.

Difficulties were encountered in testing both the glass and glass/graphite hybrids using an Izod lightweight pendulum. The specimens' energy absorbing characteristics were superior to those of the graphite/epoxy composite and thus a 250 foot-pounds system capable of delivering higher energy levels was used. The specimens already prepared for use on the overall Izod testing device were utilized. A schematic of the impact test device is shown in Figure 35.

Appendix IV presents the individual specimen test results of the test program shown in Table II. Many of the test specimens were not 100% fractured during an impact but instead were partially fractured and the semi-intact specimen was subsequently pushed through the opening in the specimen support fixture (See also Figure 60 in Appendix IV). The energy necessary to deform and push the specimen through this opening was subsequently determined for the specimens by integrating the force-displacement curve obtained for that specimen using an Instron Universal Testing Machine. This energy was last partially recovered in the elastic restoration of the semi-fractured specimen to its original-flat condition. In addition the frictional resistance of the supports to passage of the specimen, although non-recoverable, was not expended in the fracture of the laminate and depended wholly on the test setup configuration. As a result the deletion of these portions of the expended energy gave a picture of the actual energy expended in fracturing the sample, however incomplete that fracture might be.

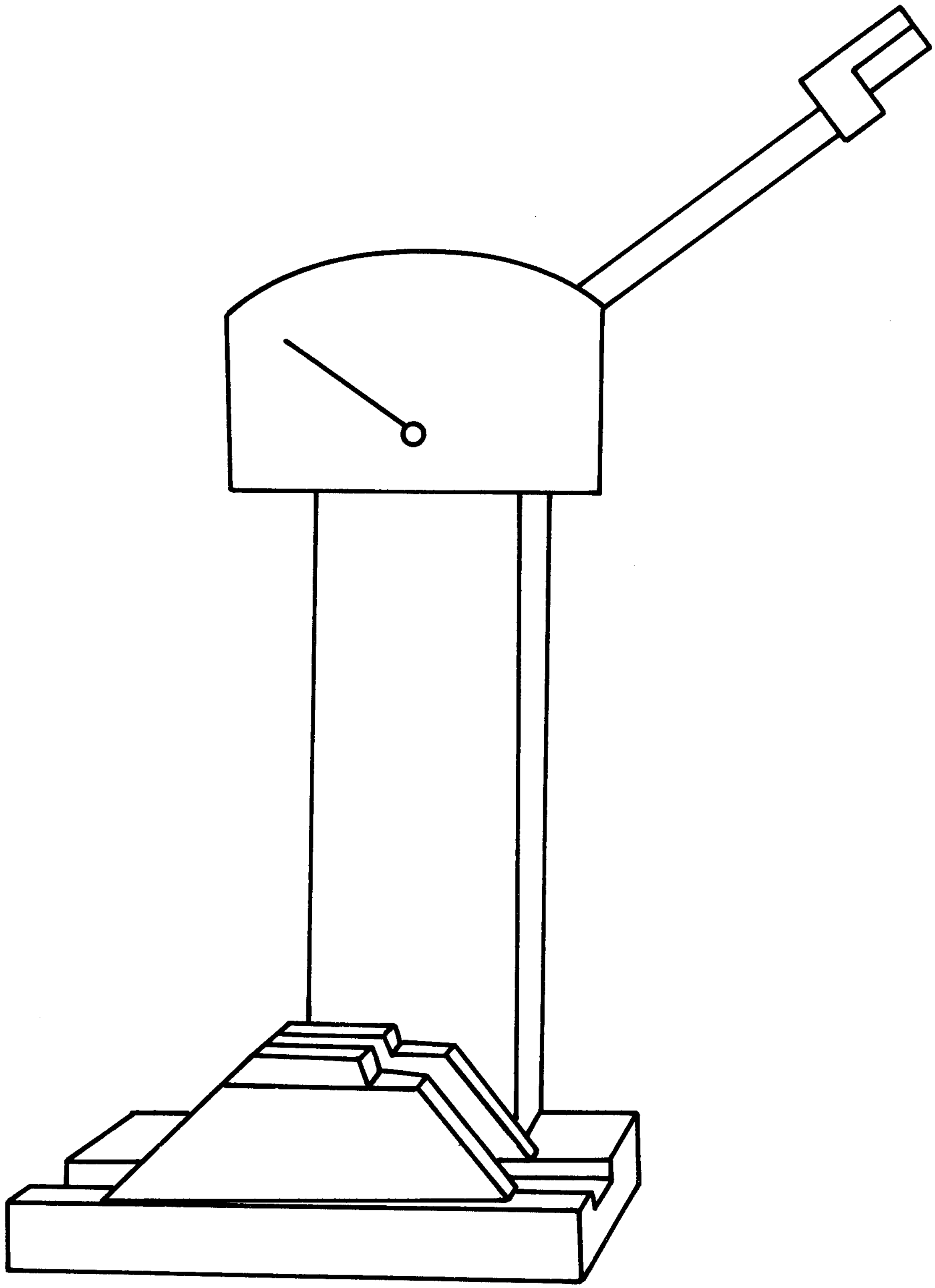


Figure 35 Schematic of Impact Test Fixture (See Also Figure 60).

A summary of these test results is shown in Figures 36 to 50. The influence of prior moisture and thermo-humidity cyclic exposures is shown as well. As can be seen in Figures 36 and 37 the impact fracture resistance of glass and graphite epoxies are considerably different, that for glass being about three times that for graphite/epoxy. The glass/epoxy appeared to be more influenced by the presence of moisture than did the graphite/epoxy. Hybridization of the unidirectional composites (Figures 38 to 40) showed a mixed behavior, but generally better impact resistance with increasing volumes of glass. In addition it is interesting to note that as the moisture conditioning progressed, the impact resistance of the hybrid composites also increased (see in Particular Figure 38 for 1:1 graphite/glass/epoxy hybrid composite.

Less improvement was evident for the 0° - 90° hybrid composites as is shown in Figures 41 - 45 and in fact the 3:1 hybrids (Figure 45) show almost no impact resistance at all. The lone exception to this was the 2:1 hybrid 0° - 90° type composite which showed a steady rapid increase in resistance to impact fracture as a function of moisture exposure. The presence of graphite 90° layers in this composite is obviously helpful in resisting impact.

Finally, the quasi-isotropic composites impact behavior is shown in Figure 46 - 50. The best performance overall for the various moisture exposure conditioning treatments was for the 3:1 Quasi-isotropic hybrids as seen in Figure 50 where the impact resistance was again as good as the all-glass/epoxy system (see Figure 46).

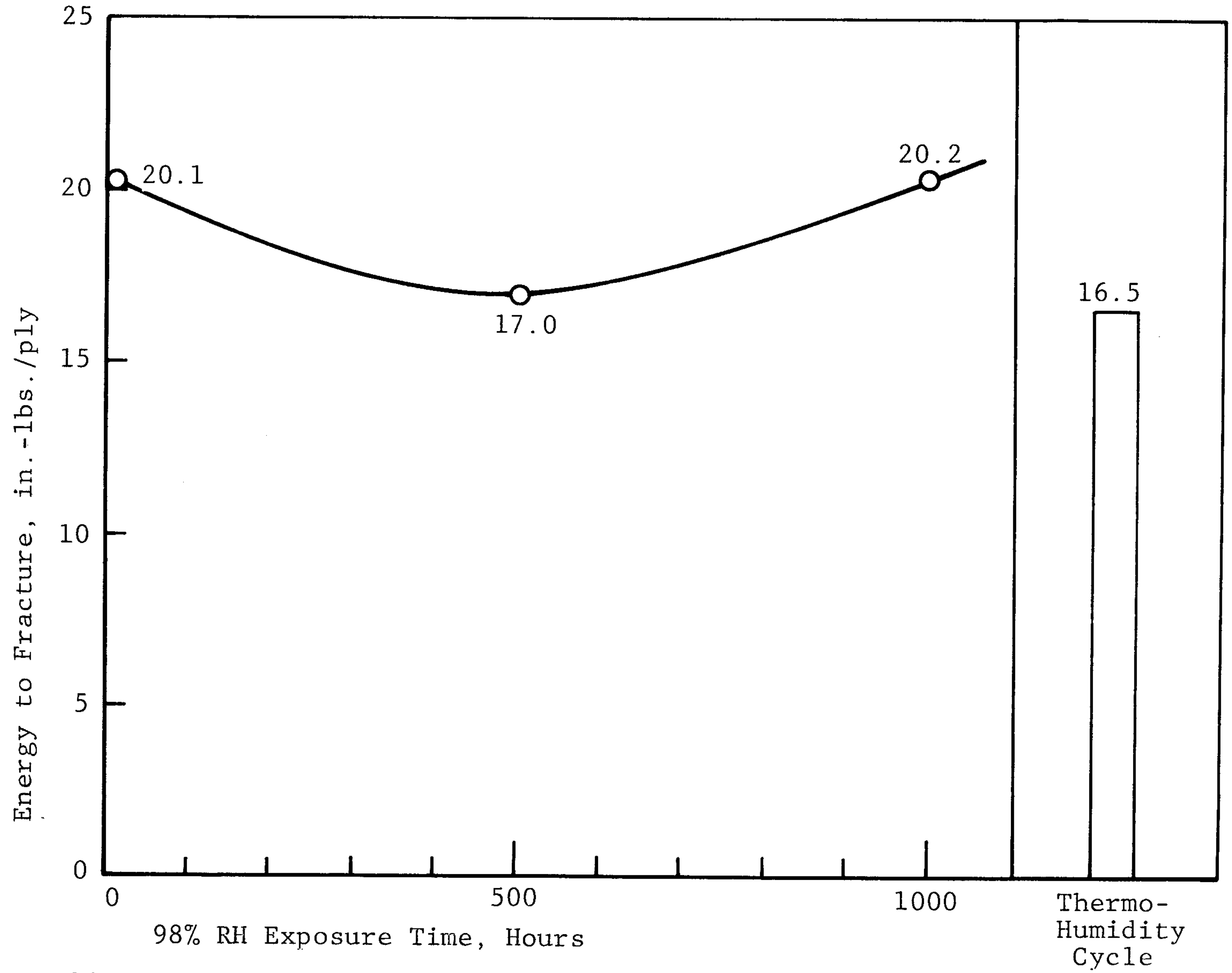


Figure 36 Impact Fracture Energy as a Function of Exposure to Moisture for S-Glass/Narmco 5208 Composites, Orientation: $[0^{\circ}L_{8}]$, 0% Graphite, by plies.

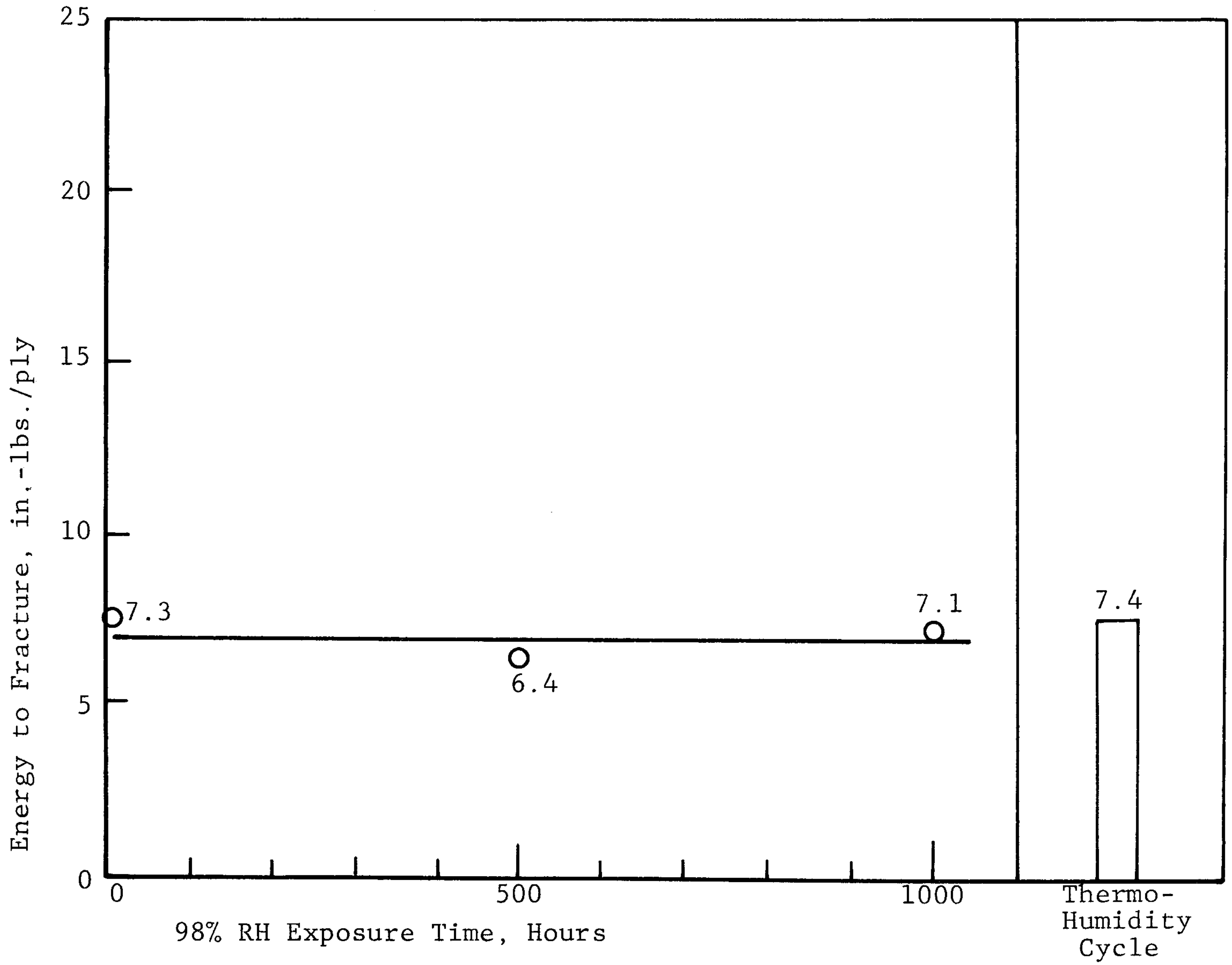


Figure 37 Impact Fracture Energy as a Function of Exposure to Moisture for T-300 Graphite/Narmco 5208 Composites
Orientation: $[0^{\circ}R_8]$, 0% Graphite, by plies.

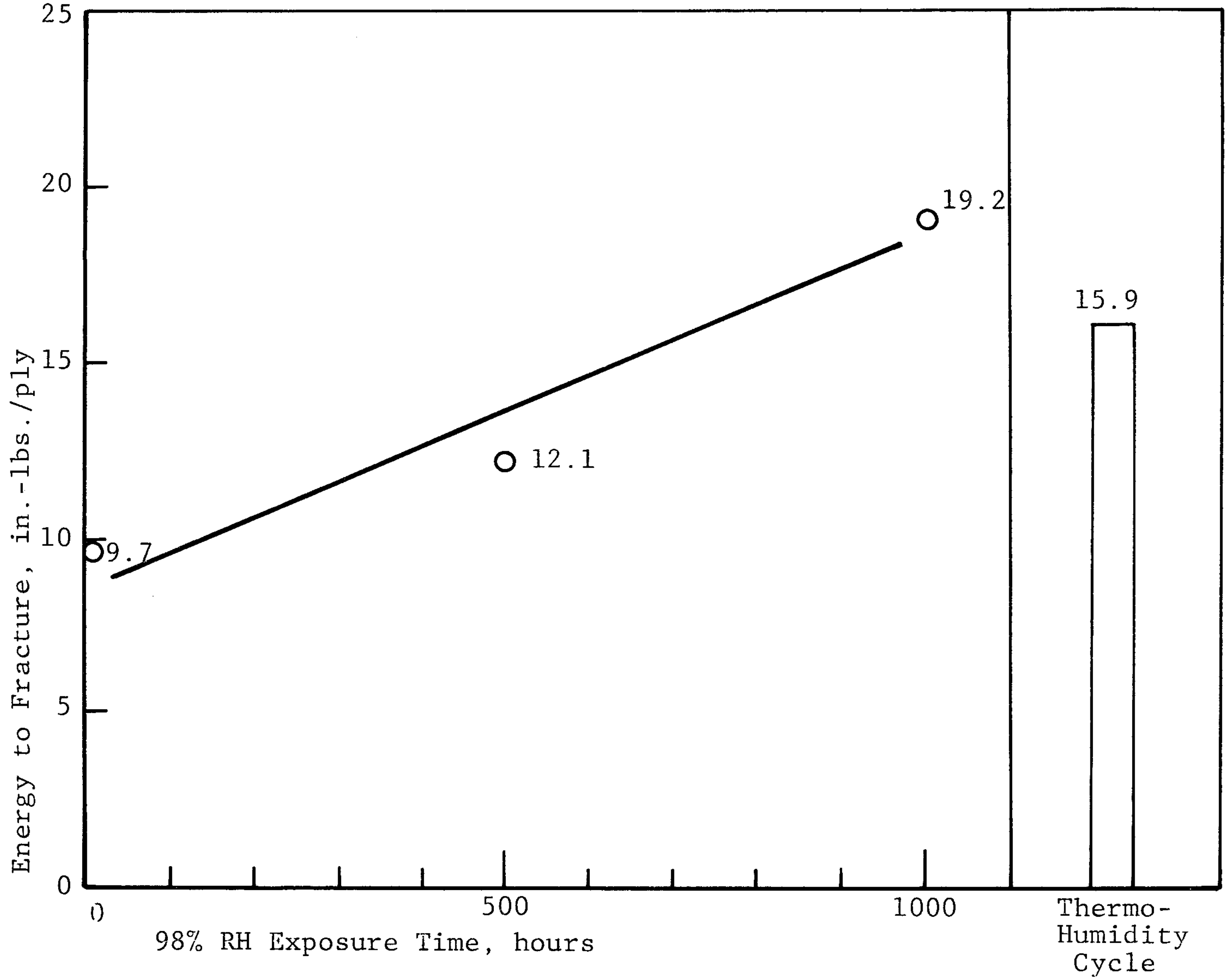


Figure 38 Impact Fracture Energy as a Function of Exposure to Moisture for S-Glass/T-300 Graphite/Narmco 5208 Hybrid Composites. Orientation: $[0^{\circ}R/0^{\circ}L/0^{\circ}R/0^{\circ}L_2/0^{\circ}R/0^{\circ}L/0^{\circ}R]$, 50% Graphite, by plies.

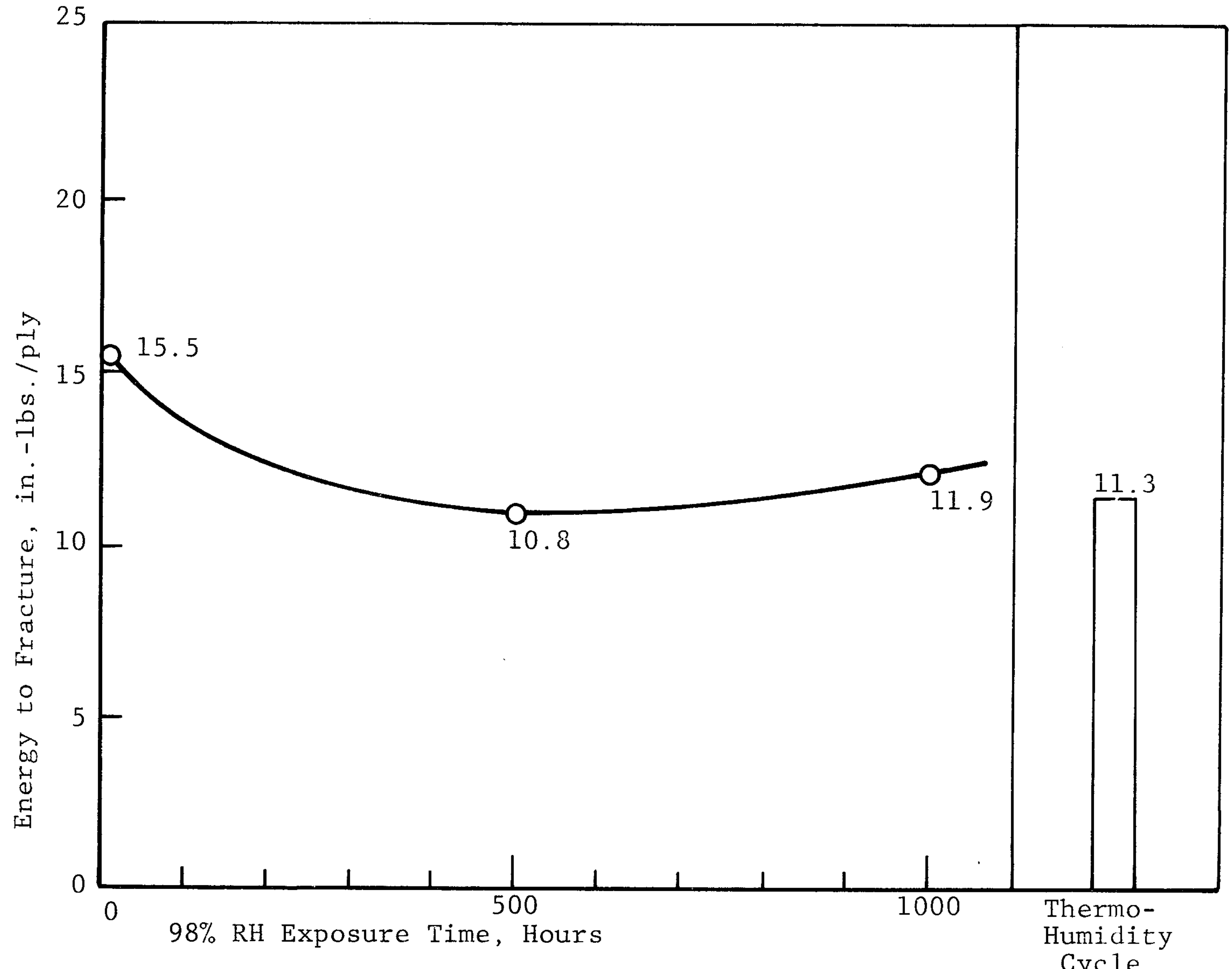


Figure 39 Impact Fracture Energy as a Function of Exposure to Moisture for S-Glass/T-300 Graphite/Narmco 5208 Hybrid Composites
Orientation: [0°R/0°L/0°R/0°R/0°L/0°R], 67% Graphite, by plies.

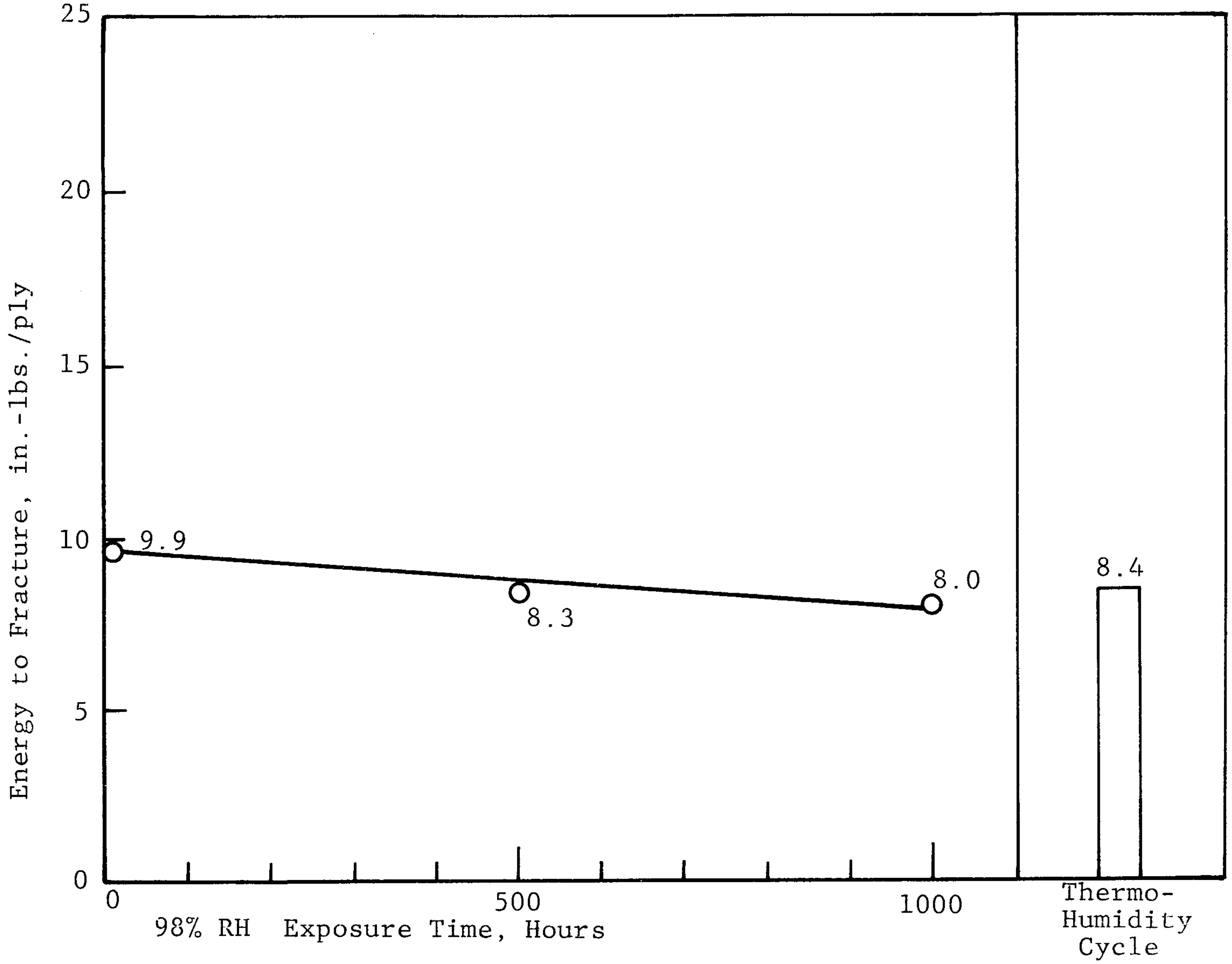


Figure 40 Impact Fracture Energy as a Function of Exposure to Moisture for S/Glass/T-300 Graphite/Narmco 5208 Hybrid Composites Orientation: $[0^{\circ}R/0^{\circ}L/0^{\circ}R_4/0^{\circ}L/0^{\circ}R]$. 75% Graphite, by plies.

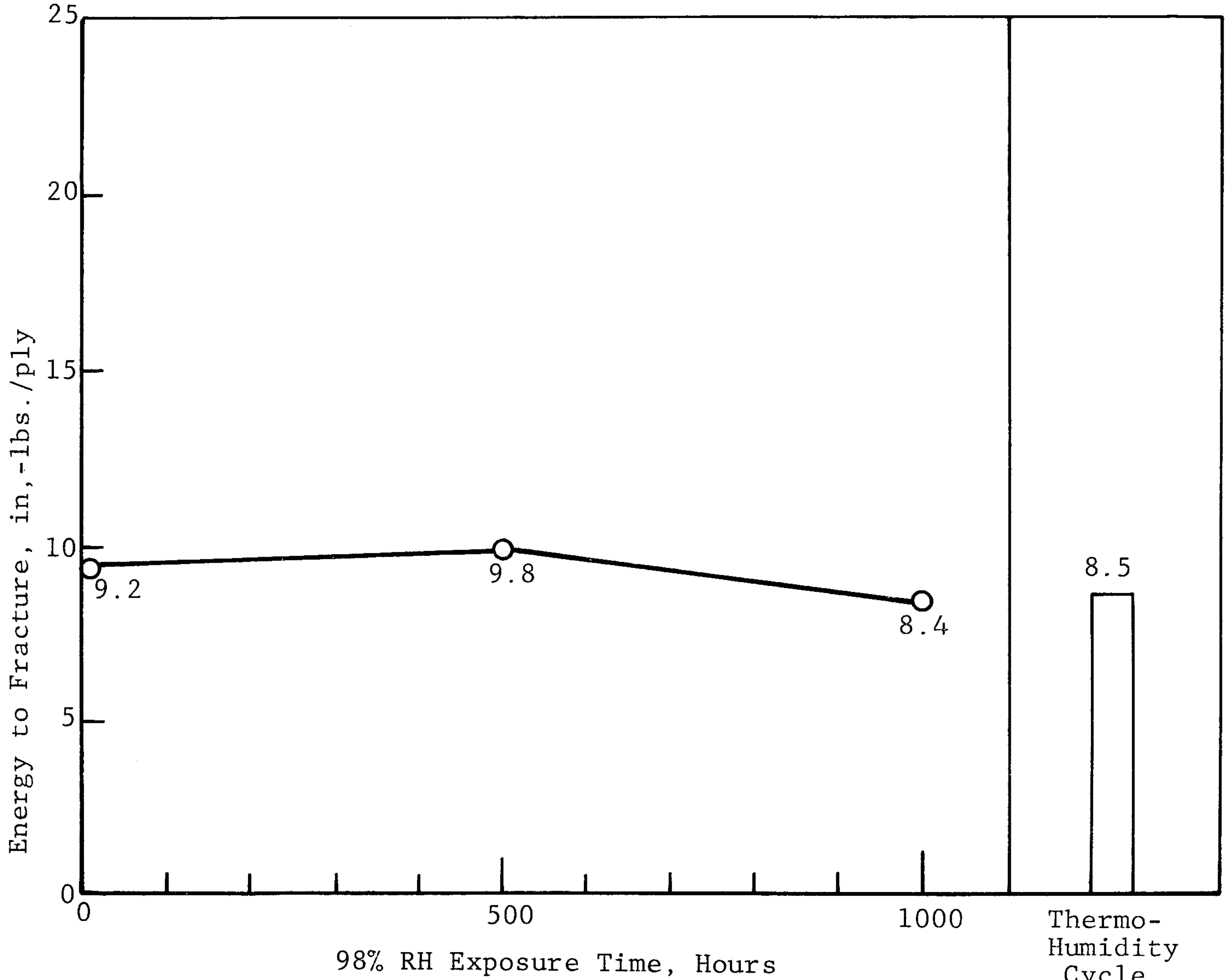


Figure 4i Impact Fracture Energy as a Function of Exposure to Moisture for S-Glass/Narmco 5208 Composites.
Orientation: $[0^{\circ}L/90^{\circ}L/0^{\circ}L/90^{\circ}L/90^{\circ}L/0^{\circ}L/90^{\circ}L/0^{\circ}L]$, 0% Graphite, by plies.

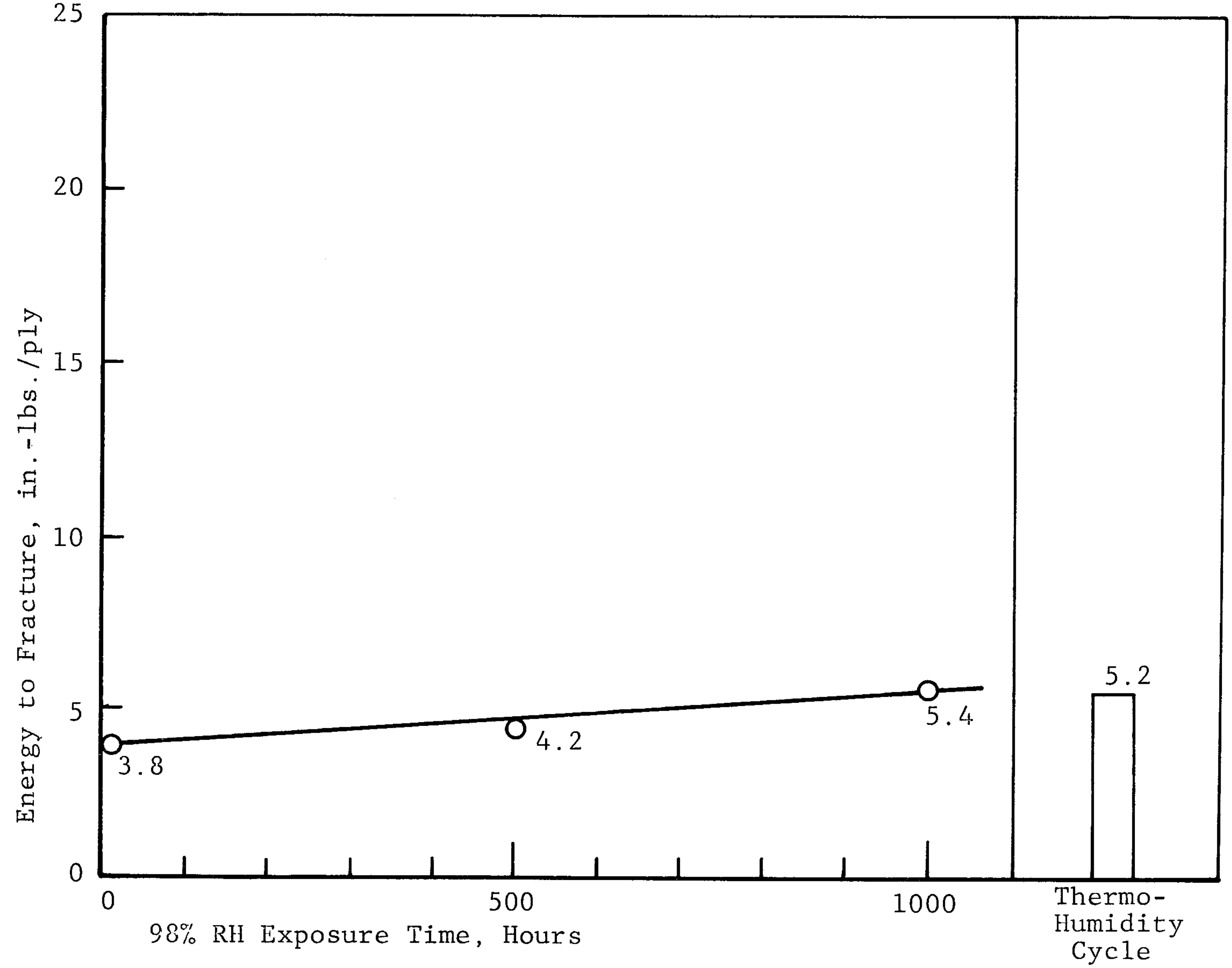


Figure 42 Impact Fracture Energy as a Function of Exposure to Moisture for T-300 Graphite/Narmco 5208 Composites.
Orientation: $[0^{\circ}R/90^{\circ}R/0^{\circ}R/90^{\circ}R_2/0^{\circ}R/90^{\circ}R/0^{\circ}R]$, 100% Graphite, by plies.

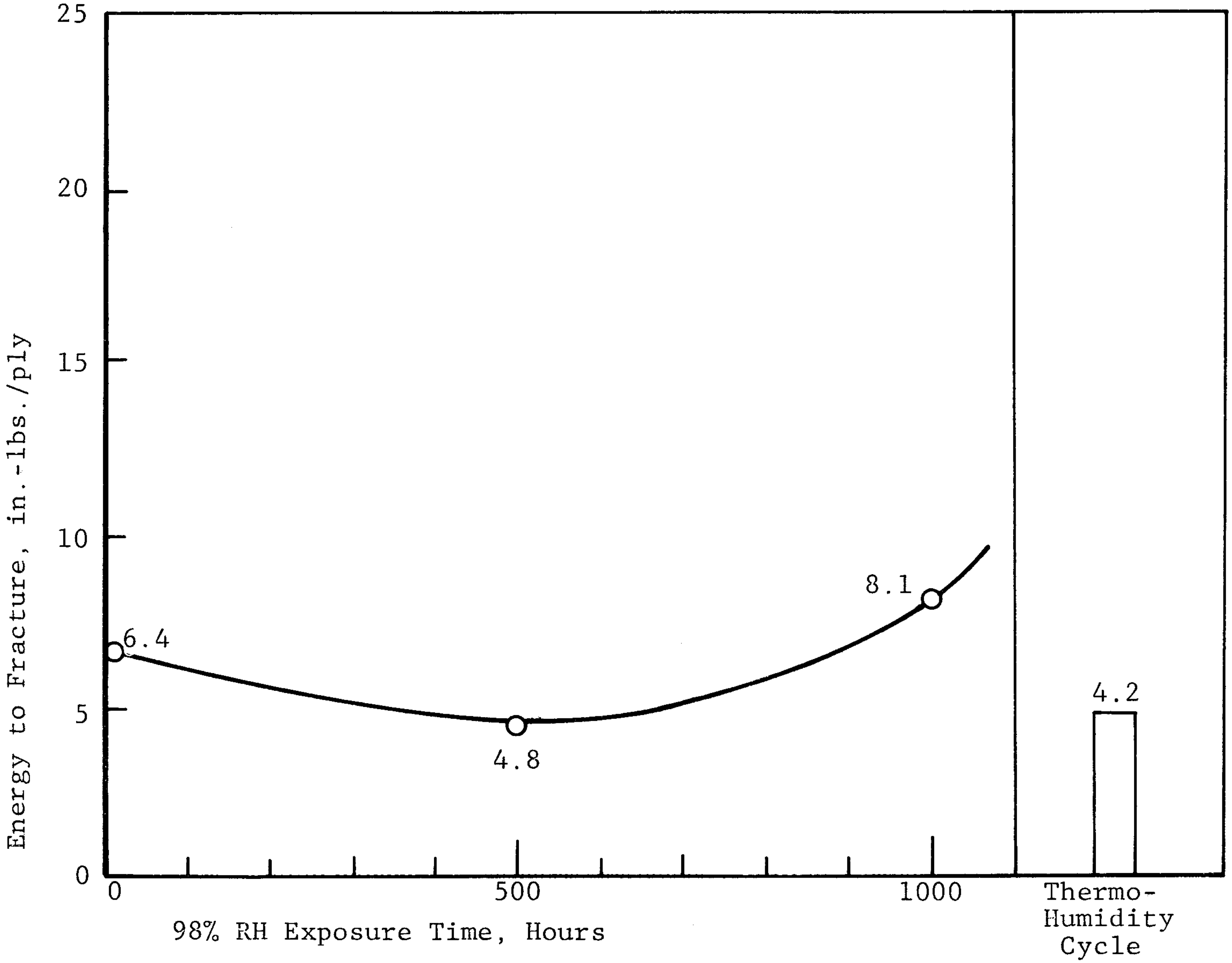


Figure 43 Impact Fracture Energy as a Function of Exposure to Moisture S-Glass/T-300 Graphite/Narmco 5208 Hybrid Composites Orientation: $[0^{\circ}R/90^{\circ}L/0^{\circ}L/90^{\circ}R_2/0^{\circ}L/90^{\circ}L/0^{\circ}R]$, 50% Graphite, by plies.

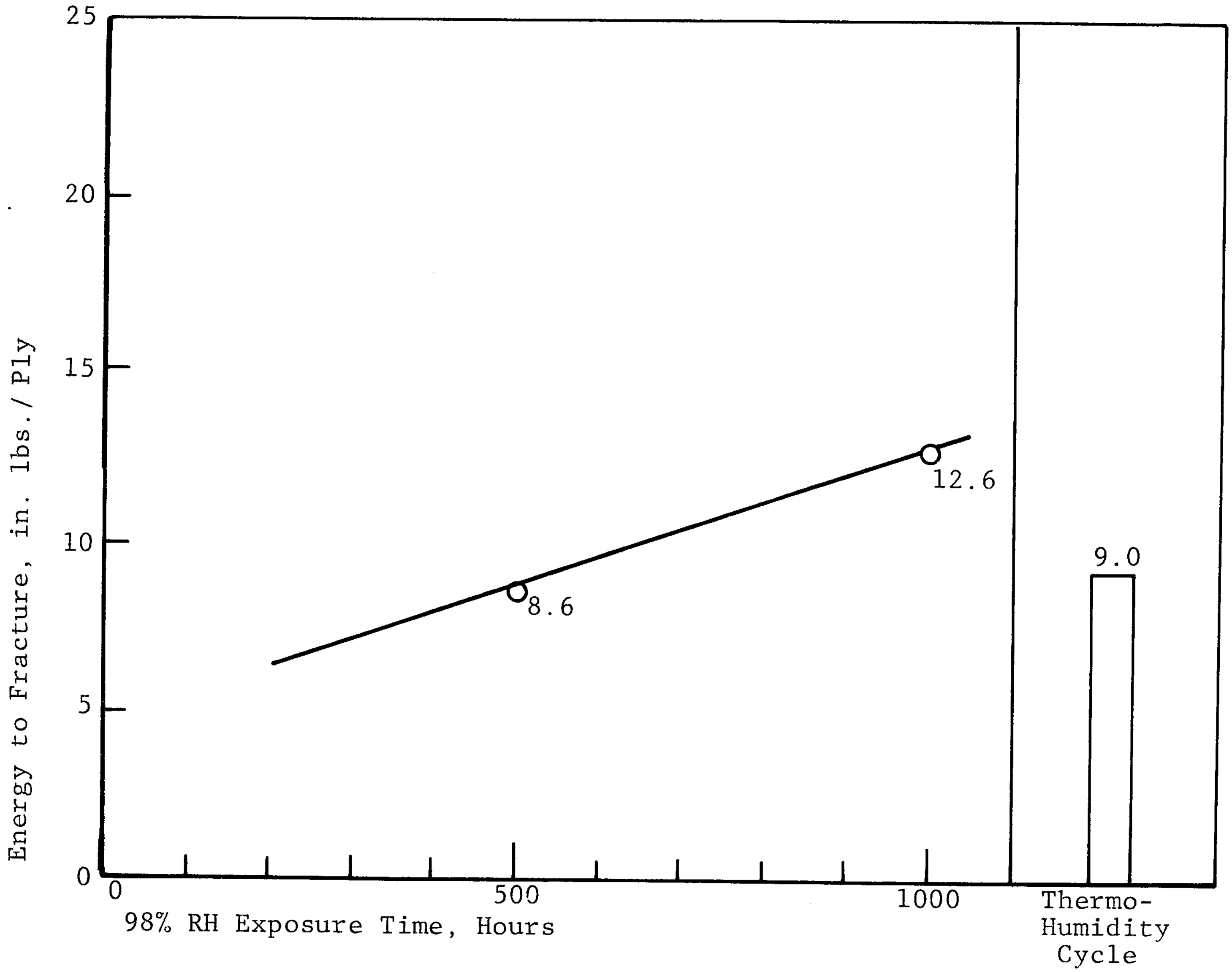


Figure 44 Impact Fracture Energy as a Function of Exposure to Moisture for S/Glass/T-300 Graphite/Narmco 5208 Hybrid Composites Orientation: $[0^{\circ}R/90^{\circ}R/0^{\circ}L/90^{\circ}L/0^{\circ}R/90^{\circ}R_2/0^{\circ}R/90^{\circ}L/0^{\circ}L/90^{\circ}R/0^{\circ}R|$, 67% Graphite, by plies.

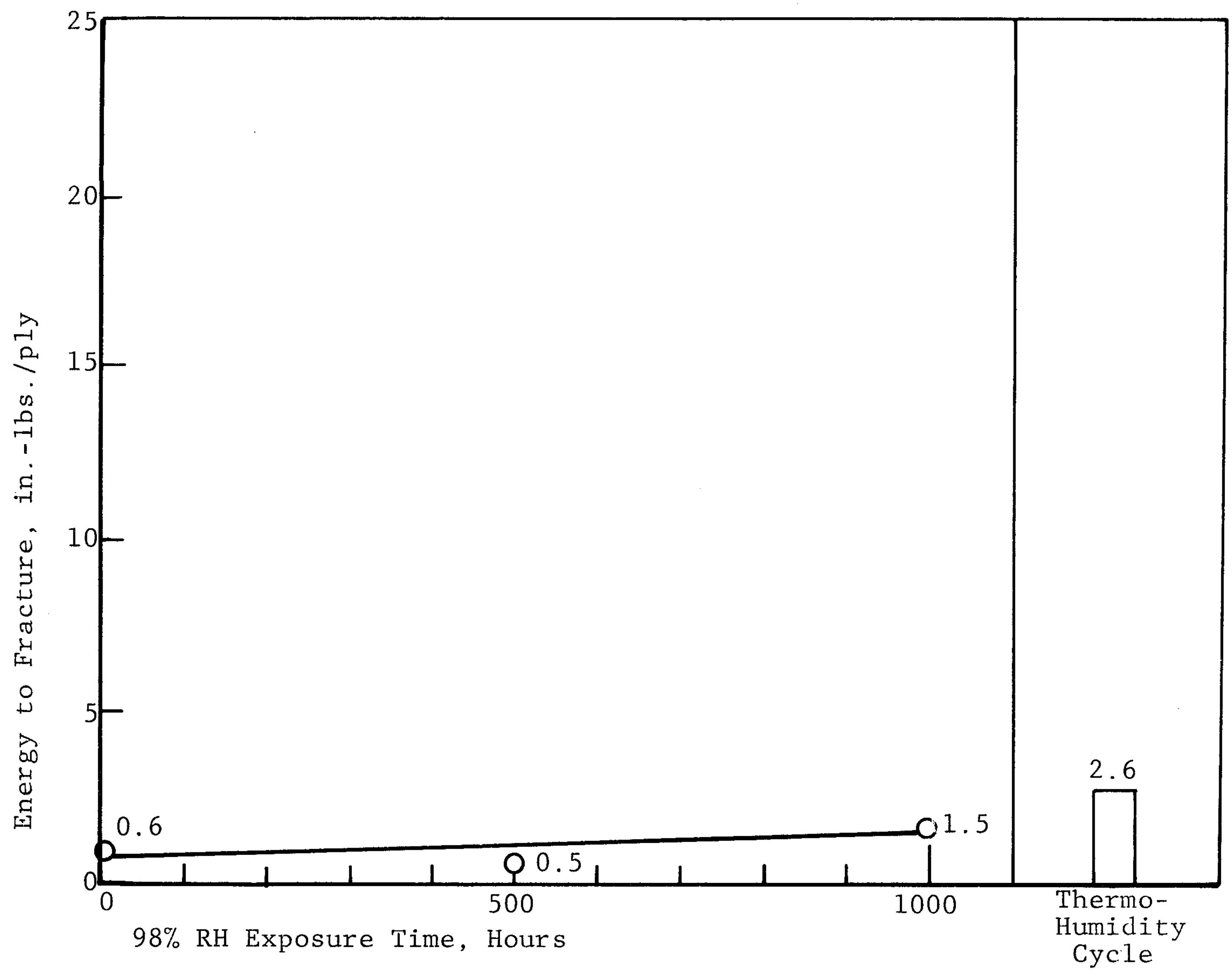


Figure 45 Impact Fracture Energy as a Function of Exposure to Moisture for S-Glass/T-300 Graphite/Narmco 5708 Hybrid Compositers, Orientation: $[0^\circ R/90^\circ R/0^\circ L/90^\circ R_2/0^\circ L/90^\circ R/0^\circ R]$, 75% Graphite, by plies.

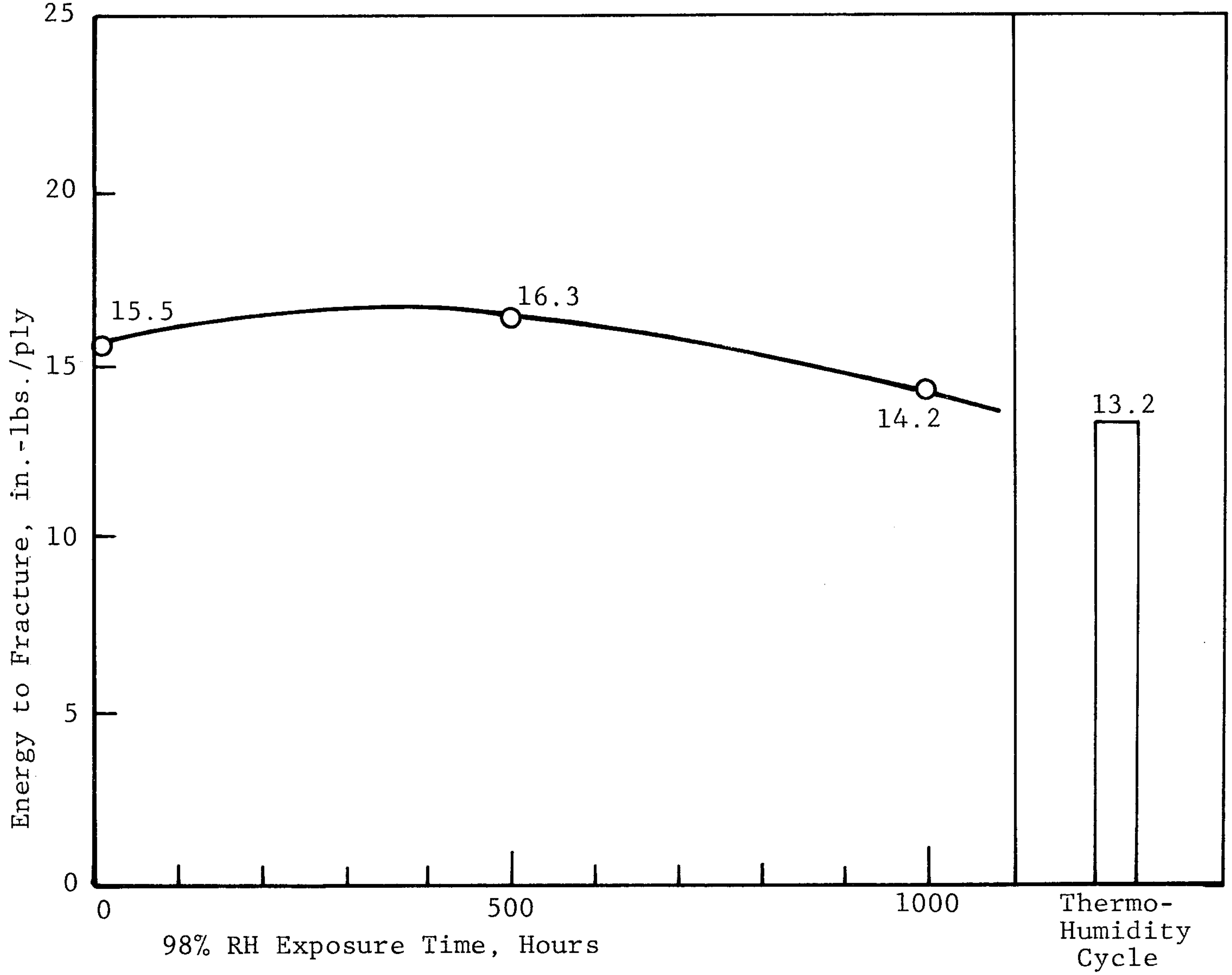


Figure 46 Impact Fracture Energy as a Function of Exposure to Moisture for S-Glass/Narmco 5208 Composites,
Orientation: $[0^{\circ}L/\pm45^{\circ}L/90^{\circ}L_2/\mp45^{\circ}L/0^{\circ}L]$, 0% Graphite, by plies.

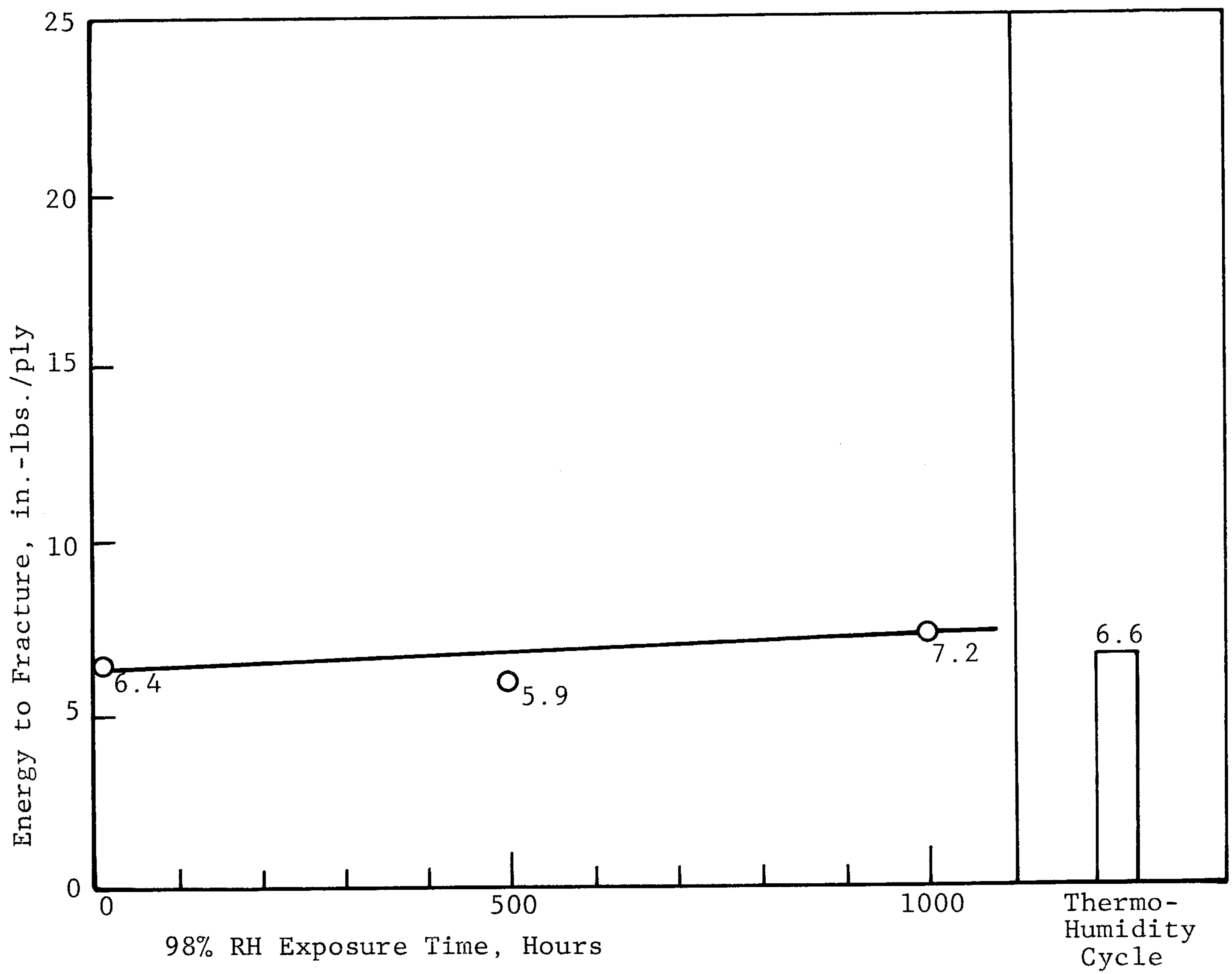


Figure 47 Impact Fracture Energy as a Function of Exposure to Moisture for T-300/Graphite/Narmco 5208 Composites.
Orientation: $[0^{\circ}R/\pm45^{\circ}R/90^{\circ}R_2/\mp45^{\circ}R/0^{\circ}R]$, 100% Graphite, by plies.

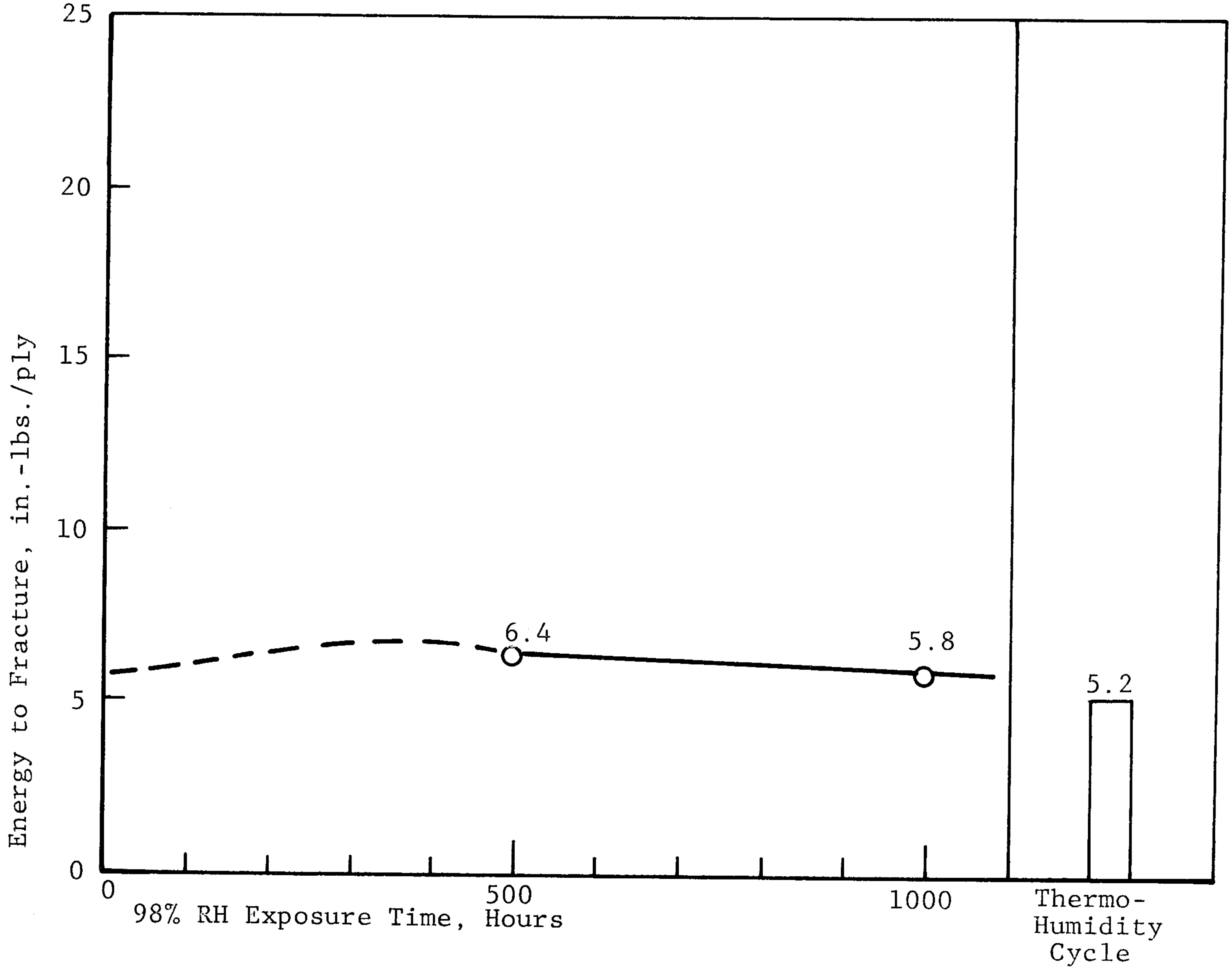


Figure 48 Impact Fracture Energy as a Function of Exposure to Moisture S-Glass/T-300 Graphite/Narmco 5208 Hybrid Composites Orientation: $[0^{\circ}R/\pm45^{\circ}L/90^{\circ}R_2/\mp45^{\circ}L/0^{\circ}R]$, 50% Graphite, by plies.

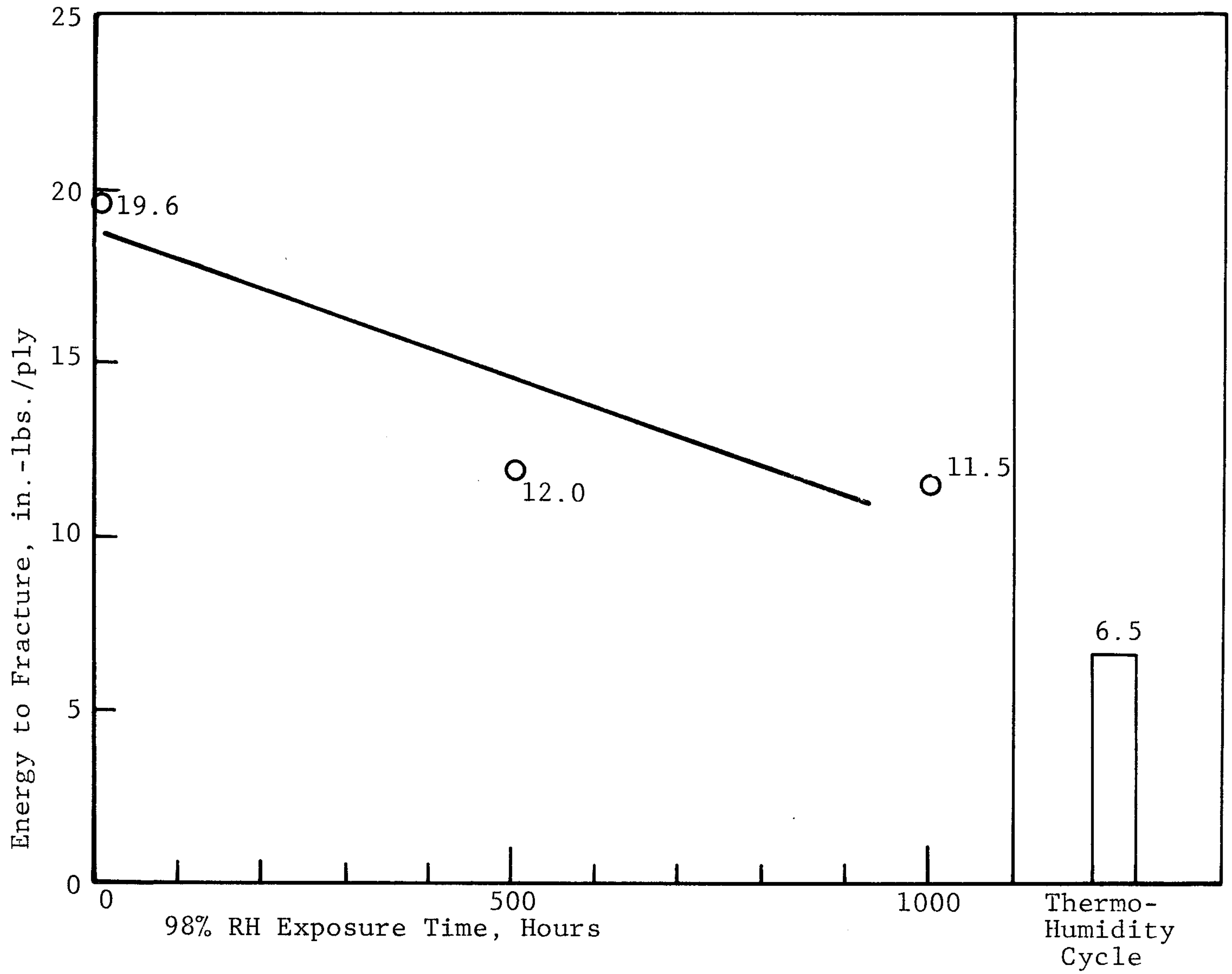


Figure 49 Impact Fracture Energy as a Function of Exposure to Moisture for S-Glass/T-300 Graphite/Narmco 5208 Hybrid Composites, Orientation: $[0^\circ R/90^\circ R/\pm 45^\circ L/90^\circ R/0^\circ R_2/90^\circ R/\mp 45^\circ L/90^\circ R/0^\circ R]$, 67% Graphite, by plies.

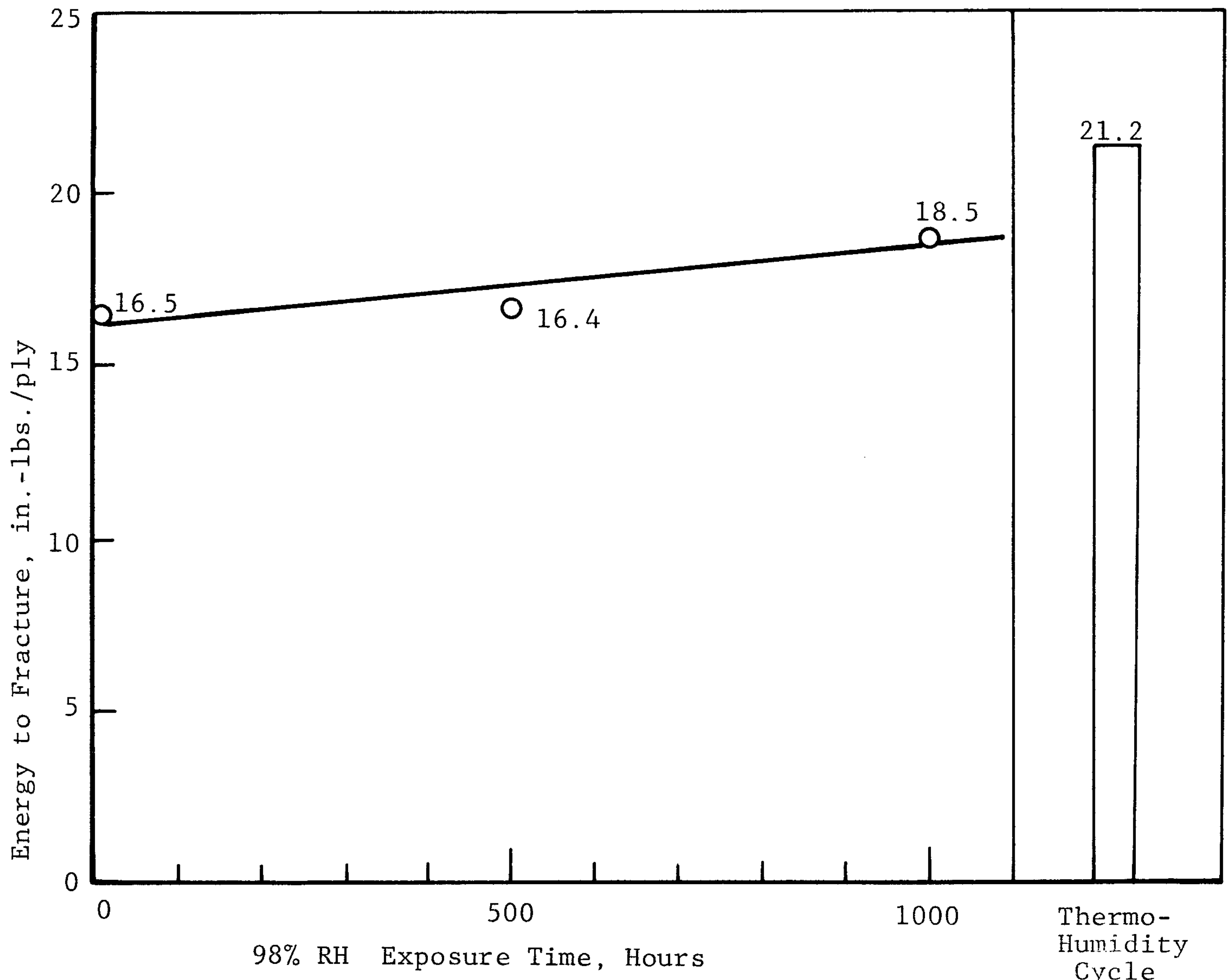


Figure 50 Impact Fracture Energy as a Function of Exposure to Moisture for S-Glass/T-300 Graphite/Narmco 5208 Hybrid Composites, Orientation: $[0^{\circ}R/90^{\circ}R/0^{\circ}R/90^{\circ}R/\pm45^{\circ}L/90^{\circ}R/0^{\circ}R_2/90^{\circ}R/\mp45^{\circ}L/90^{\circ}R/0^{\circ}R/90^{\circ}R/0^{\circ}R]$, 75% Graphite, by plies.

SECTION VI

6.0 SUMMARY AND CONCLUSIONS

The results of this program are summarized below as follows:

- Hybrid graphite/glass/epoxy composites can be manufactured with properties at least as good as the high modulus all-graphite/epoxy composites and at considerably reduced costs over an all-graphite composite.
- The 1000 hours at 98% RH exposure should be considered as the one for accelerated aging programs since it points out the fatigue behavior of the composites most clearly.
- Graphite/epoxy, glass/epoxy and graphite/glass/epoxy composites appear to show fiber/matrix decoupling during fatigue causing an increase in the 0° fatigue performance, a decrease in the 90° fatigue resistance and a mixed modal behavior in quasi-isotropic laminates.
- The residual elastic modulus of graphite/epoxy and glass/graphite/epoxy hybrid composites remains constant at least out to the 10^7 cyclic life level even after high humidity cycling.
- The elastic strength decreased as the cyclic exposure increases and Poisson's ratio for the 0° material increases slightly with added stress cycling.
- The impact resistance of hybrid glass/graphite/epoxy composites is improved over the all-graphite/epoxy composites to a level frequently as good as the all-glass/epoxy composites.

- The presence of moisture does not degrade the impact resistance of either single phase or hybrid composites and frequently improves the impact energy to fracture as the resin plasticizes.
- Overall, the hybrid composites not only can produce cost effective composites but actually can possess mechanical properties considerably improved over the single phase systems.
- A comparison of the transverse fatigue behavior of the all glass systems (recall Figure 10) and the hybrid glass/graphite system (e.g. Figure 17) is in order. This shows that the transverse fatigue strengths are higher for the all-glass composite, where the interfacial bonding is expected to be good, than for the hybrid system where some graphite/epoxy interfacial bonds are present. The 1000 hour high moisture exposures on these two systems, however, results in a very similar residual fatigue strength. This is taken to indicate that the principal degradatory mechanism of moisture is on the interface between the fiber and the matrix and that the graphite composite degradation will be no worse than that for glass composites.

Future efforts should be made:

- To analyze the effect of stacking arrangements including fiber orientation and siting of plies on the fatigue life of graphite/glass/epoxy hybrid composites
- to understand the influence of prolonged loading (creep) on the strength of hybrid composites
- and to investigate the influence of alternative matrix and fibers so as to establish the influence of material variables in the fatigue and creep behavior of hybrid composites.

APPENDIX I

LAMINATE AND SPECIMEN FABRICATION DETAILS

APPENDIX I LAMINATE AND SPECIMEN FABRICATION DETAILS

This appendix describes the method by which the basic composite and hybrid composite materials were prepared for use on this program.

II.1 Material

Thornel 300 Graphite/Narmco 5208 is a current graphite/epoxy composite material which is being investigated widely for application to aerospace structural components. This material is available in a wide variety of forms but is generally utilized in the prepreg tape form.

The specification to which the Thornel 300 Graphite/Narmco 5208 material was ordered was:

General Dynamics specification: FMS 2023, Type III, Form A. "Graphite Fiber High Tensile Strength, Intermediate Modulus, Epoxy or Modified Epoxy Resin Impregnated", dated November 30, 1972 and all amendments.

This specification has been widely used throughout the industry and is available directly from General Dynamics Convair Division Fort Worth, Texas.

The glass fiber/epoxy was the S-glass rovings/Narmco 5208 system. It was also utilized in the 3 inch wide prepreg tape form.

II.2 Material Procurement

Ten lbs. of the graphite prepreg and twelve lbs of the glass prepreg were utilized during this program. The material

was ordered in the 3" wide continuous tape form under the trade name Rigidite 5208/Thornel 300 Type III, Form A. Two rolls of batch No. 3 were delivered to IITRI to meet this order. The resin (solids) content, room temperature and 350^{o}F flexural strengths and moduli and the horizontal shear strengths were determined for the 0^{o} orientation by Whittaker Corporation Costa Mesa, California. The certification report by Whittaker that this batch conforms to Spec. FMS 2023 is presented in Table V.

Upon reciept of the materials from the prepregger, quality assurance panels were prepared. Longitudinal and transverse flex and 0^{o} interlaminar shear specimens were cut from these panels and tested in accordance with recommended advanced composites test procedures. The results are shown in Table VI.

On the basis of these test results the materials were adjudged suitable for use on this program.

I.3 Laminate Fabrication

All lamina, laminates, hybrids and specimens were prepared at IITRI for use on this program.

The fabrication techniques followed at IITRI have been discussed in reference 1. An autoclave provided the pressure and temperature necessary to cure the Narmco 5208 Epoxy in accordance with the following cure schedule recommended by General Dynamics for fabricating panels:

1. Full vacuum (26" HG) is applied to the bagged green layup.
2. The panel is heated from room temperature to 275^{o}F + 5^{o}, -10^{o}F in 40 $\pm$ 8 minutes (corresponding to a 4 to 6 degrees F/minute heat up rate)

Table V

WHITAKER CORPORATION MATERIAL CERTIFICATION REPORT

NARMCO Materials, Inc.
A Subsidiary of Celanese Corp.
600 Victoria Street
Costa Mesa, California 92627

CERTIFIED TEST REPORTS

SOLD TO

IIT Research Institute
Purchasing Dept.
10 West 35th Street
Chicago, Illinois 60616

COSTA MESA
LIBERTY 8 1144
TWX
213-273-4192

NO. 66- 29869	INVOICE NUMBER
DATE 11-6-74	PAGE 1 OF 1
CUST ORDER NO 28596 Mack	DATE 10-28-75

TESTING RESULTS

ITEM #1

~~MATERIAL~~ Rigidite 5208-S901-3"

Batch #3

Roll	Amount	Resin Content	Mfg. Date	Test Date
3	5.6 lbs.	32%	9-3-74	9-3-74
5	5.4	31		

Volatiles: 0.2%

Warranty expires: 2-6-75 @ 0°F.

This is to certify that the above material was manufactured, tested and found to conform to the applicable specification, and terms of the purchase agreement, as indicated by the above test results.

Quality Control Representative

Table VI

IITRI QUALITY ASSURANCE MECHANICAL PROPERTY TEST RESULTS FOR T-300 GRAPHITE/NARMCO 5208 AND S-GLASS ROVINGS/NARMCO 5208 PREPREG MATERIALS

T300 Graphite/Narmco 5208

0° Flex strength (ksi)	:	245
90° Flex strength (ksi)	:	8.5
Interlaminar Shear Strength (ksi)	:	14.7

S-Glass/Narmco 5208 (Batch 3)

0° Flex strength (ksi)	:	231
90° Flex strength (ksi)	:	11.8
Interlaminar Shear Strength (ksi)	:	11.8

3. The layup is held at full vacuum and 275°F + 5°F -10°F for 60 ± 5 minutes.

4. Pressure is then increased to 80 psi ± 5 psi. The vacuum is vented to outside air when the pressure has reached 25 psi.

5. Upon reaching 85 ± 5 psi, the temperature is increased to 355°F + 10°F -5°F in 15 ± 3 minutes.

6. The system is held at 85 psi ± 5 psi and 355°F + 10°F -5°F for 120 ± 5 minutes.

7. The system is then cooled to 140°F maintaining the 85 psi ± 5 psi pressure in not less than 30 minutes.

8. The panels are postcured subsequently for 240 ± 5 minutes at 400°F ± 10°F. The heatup rate for postcuring panels is from RT to 400°F in 64 ± 10 minutes.

Throughout the postcure, the panels are loosely supported between two layers of 1/2 to 3/4 inch thick aluminum honeycomb core.

The quality assurance panel layups consisted of 15 plies covered with 3 plies of 181 bleeder cloth and 1 ply of 181 vent cloth. Fiber volumes of approximately 68% were obtained using a top surface caul plate.

I.4 Quality Control Procedures

All laminates were examined using ultrasonic C-scan NDT procedures. The orientations and ply arrangements for the various laminates were discussed in the body of the report. To assist in this effort an N.D.T. test panel, with voids purposefully placed on the inside of the panel was prepared. The panel was an eight ply 0°, 90°, 0°, 0°, 0°, 0°, 90°, 0° with the flaws between the middle two zero degree plies. The panel measured 6" x 14" and contained 1) a piece of masking tape, 2) a strip of polyethylene film, 3) a strip of teflon vent film 4) a section of release paper. 120 cloth was added to the laminate in the areas not occupied by the various flaws so as to maintain continuity of thickness over the panel area. This panel was used to establish the gate for the C-scan for

acceptance or rejection of all test panels.

Typical C-scans of acceptable panels are shown in Figures 51 through 57. Two panels with unacceptable portions near the edge of the panels are shown in Figures 58 and 59. These portions were removed from the plates prior to tabbing and cutting and were not used in the test program. The remaining samples were checked visually to ascertain their quality and were found acceptable for use on the program.

I.5 Specimen Fabrication Procedures

This section briefly lists the test specimens and procedures utilized for generating the data during this program. A detailed description of the test specimens, specimen fabrication procedures and test equipment is found in Reference 1.

The same specimen configuration was utilized for tension and fatigue (R = 0.1) tests. The IITRI straight-sided tab ended coupon was utilized for these properties. After environmental conditioning and/or fatigue cycling each static tensile specimen was fitted with three electrical-resistance foil strain gages.

The specimens used for all flexural testing was the fifteen ply, coupon universally used for testing advanced composites. Specimens were loaded in a 3 (0° coupons) or 4-point (90° coupons) bending fixture. Elevated temperature tests were conducted in a Missimer circulating air oven and loads were applied in tension to a flexural test rig.

The interlaminar shear strength of oriented fiber composites was determined on short beam shear specimens. Elevated temperature tests were performed with the assistance of the fixture described above.

The overall dimension of the impact specimens are shown in Figure 60. The thicknesses of the individual base laminates and hybrid composites varied somewhat depending on the number of plies.

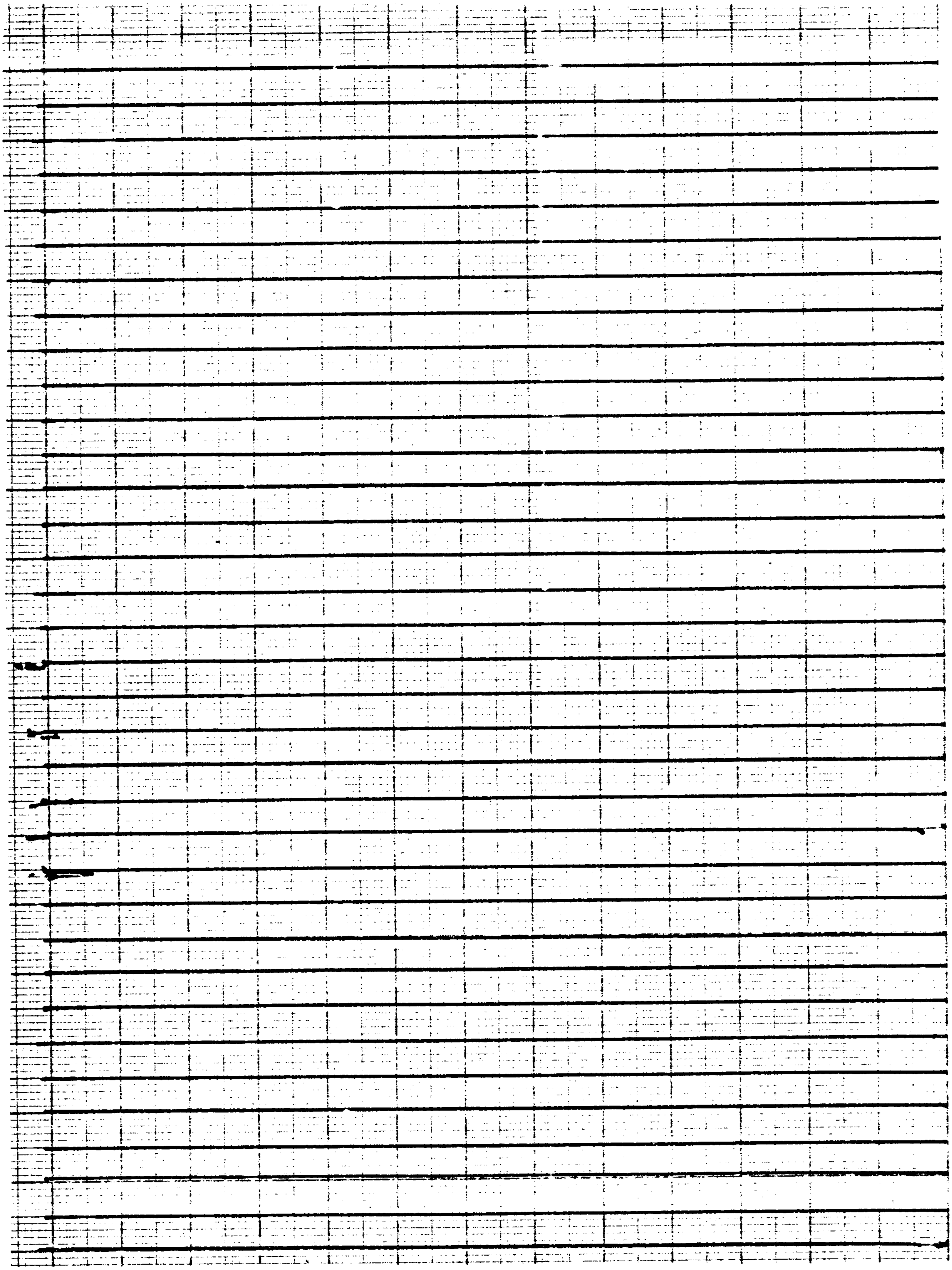


Figure 51 ULTRASONIC C-SCAN FOR ACCEPTABLE 8 PLY 0° T300 GRAPHITE/NARMCO 5208 COMPOSITE PANEL

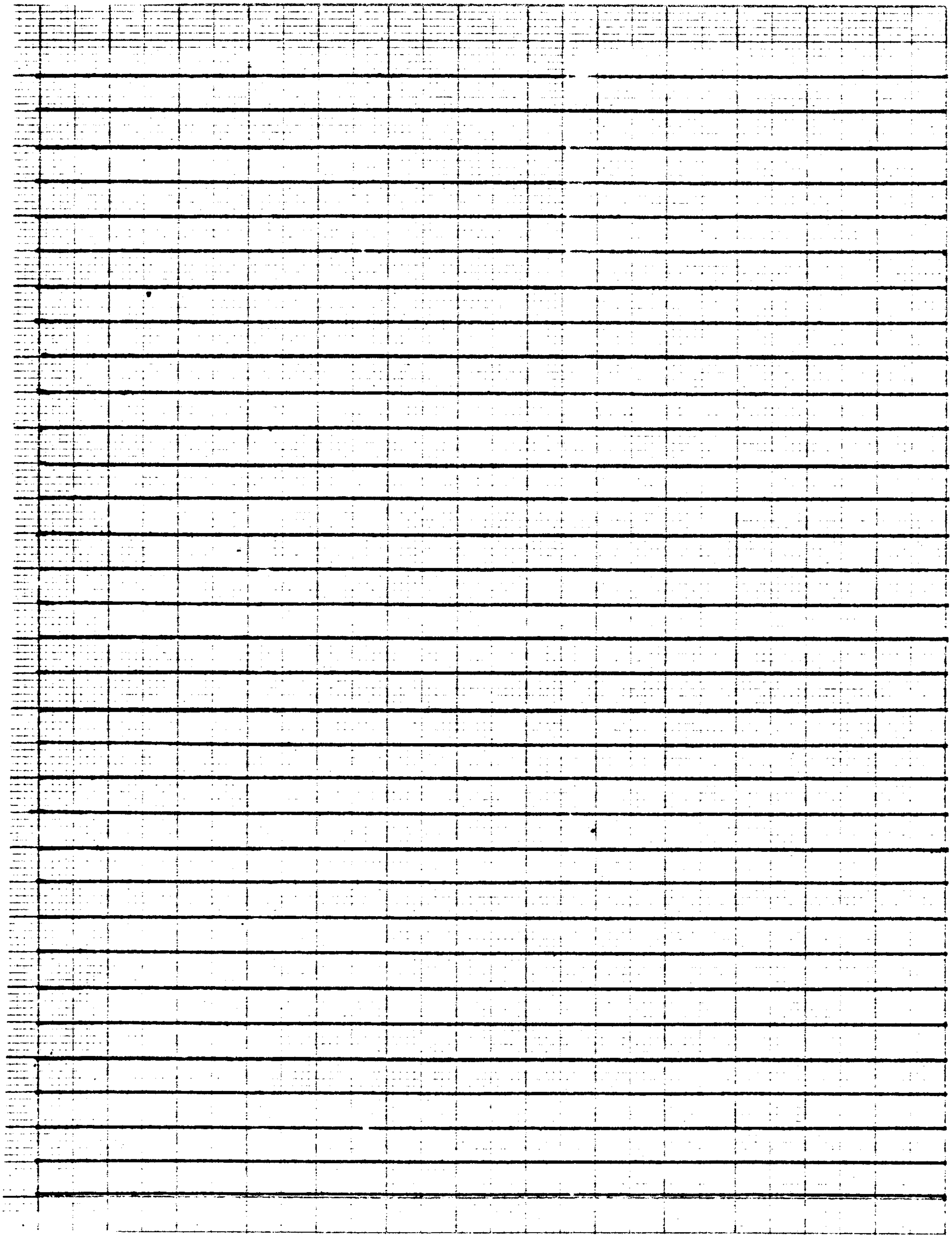


Figure 52 ULTRASONIC C-SCAN FOR ACCEPTABLE $0^{\circ}/90^{\circ}$ T300 GRAPHITE/NARMCO 5208 COMPOSITE PANEL

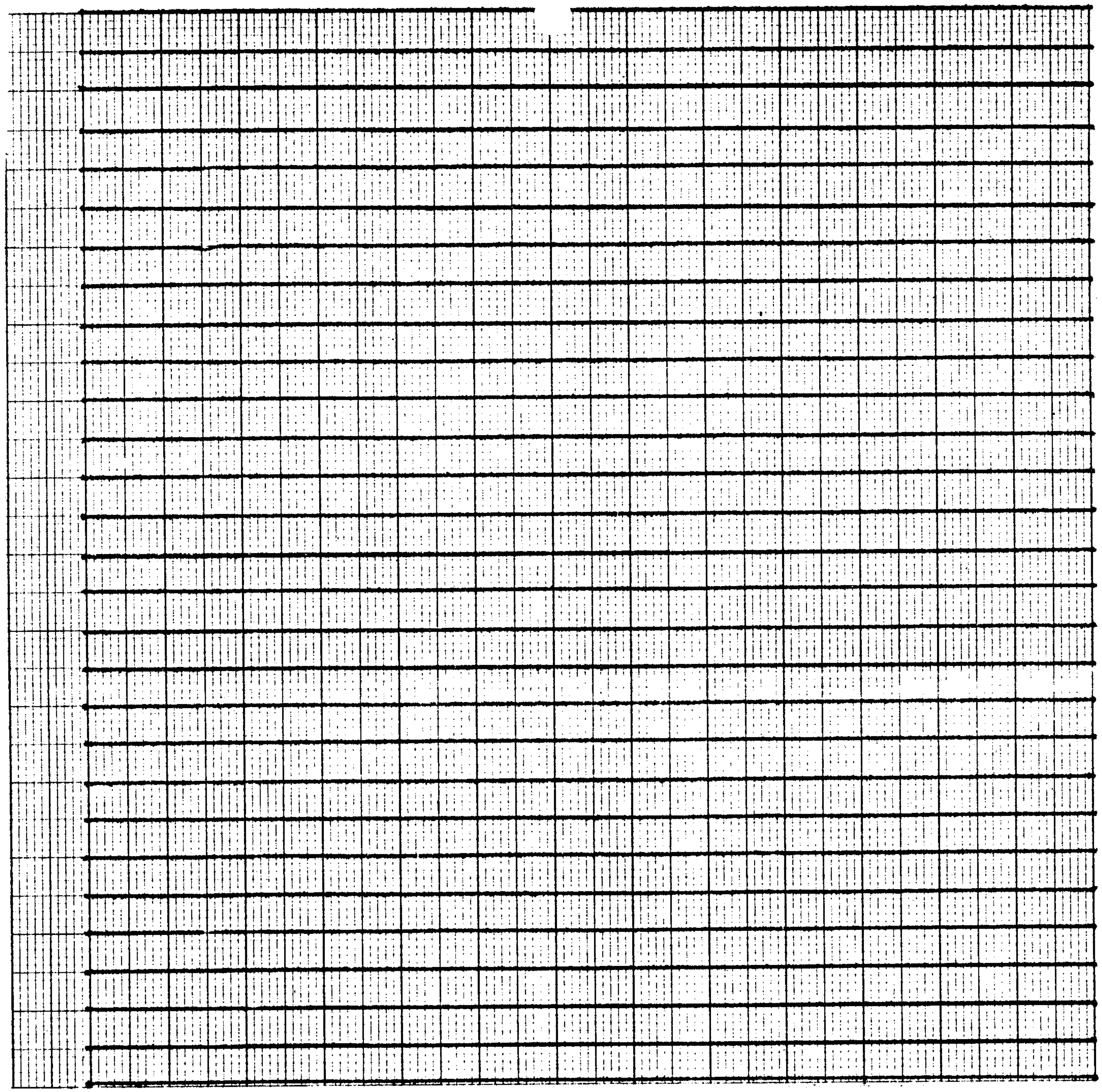


Figure 53 ULTRASONIC C-SCAN FOR ACCEPTABLE $0^{\circ}/\pm 45^{\circ}/90^{\circ}$ T300 GRAPHITE/NARMCO 5208 COMPOSITE PANEL

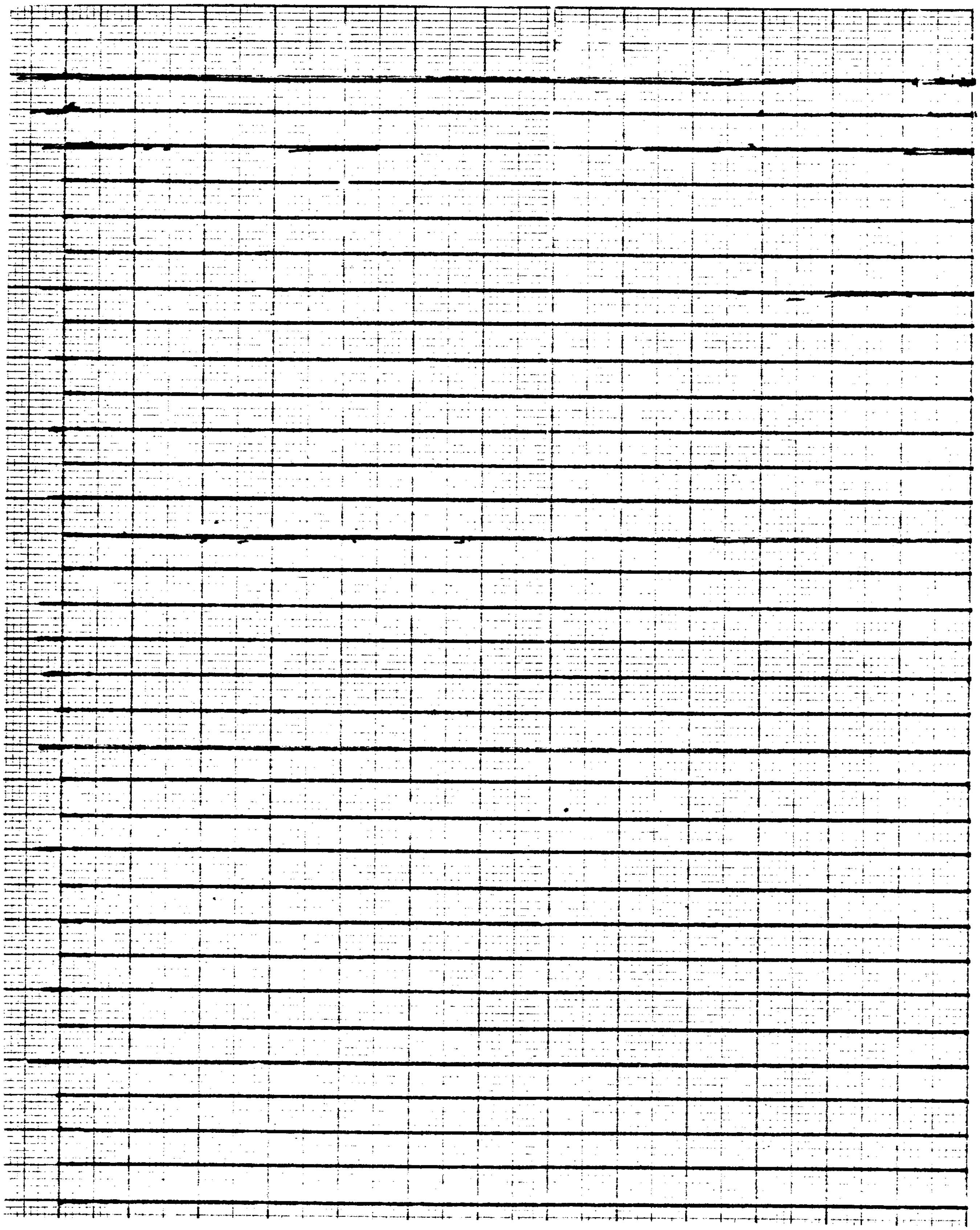


Figure 54 ULTRASONIC C-SCAN FOR ACCEPTABLE 8 PLY $0^{\circ}/90^{\circ}$ T300 GRAPHITE/S-GLASS/NARMCO 5208 HYBRID COMPOSITE PANEL

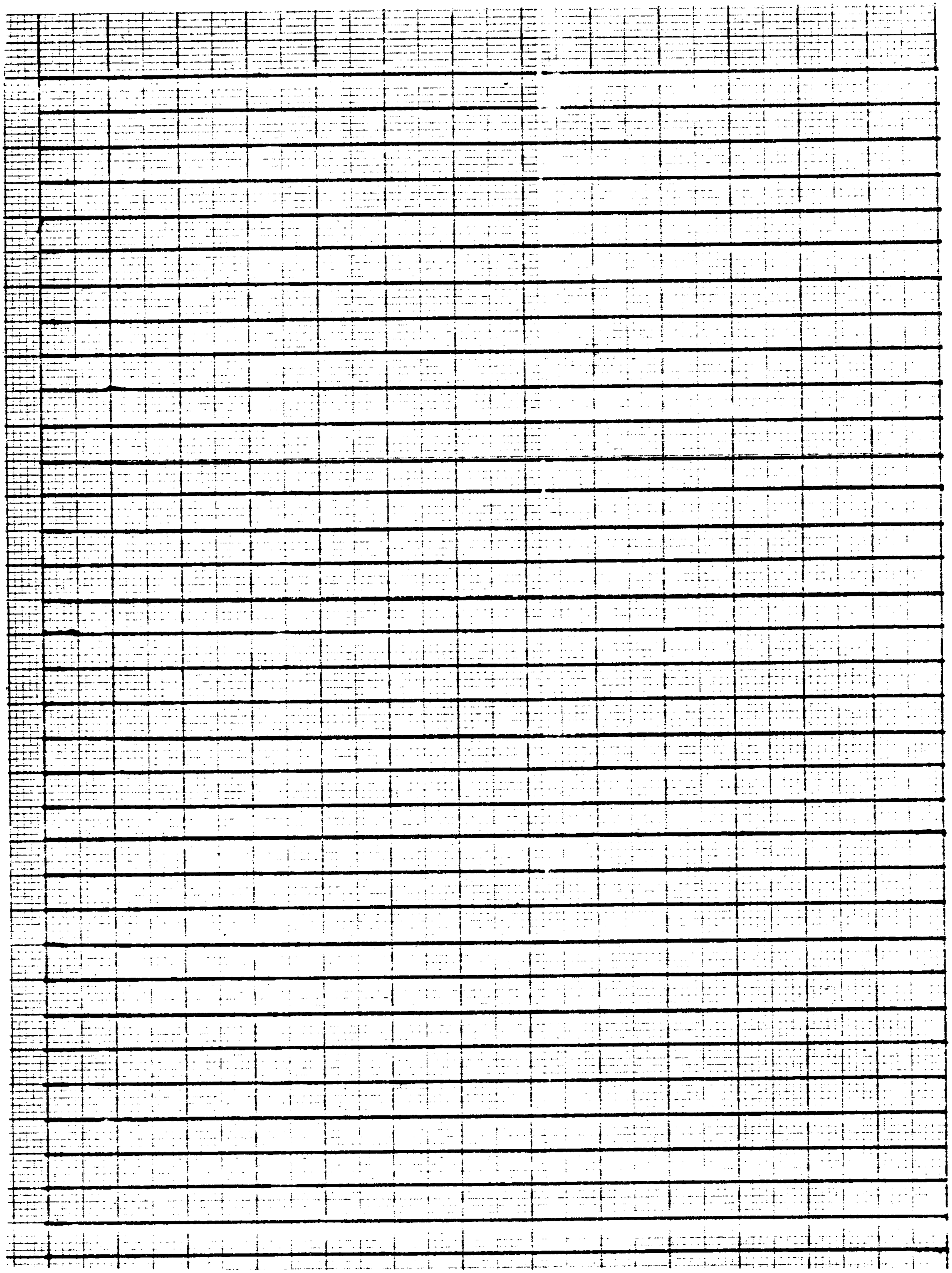


Figure 55 ULTRASONIC C-SCAN FOR ACCEPTABLE 12 PLY $0^{o}/90^{o}$ T300 GRAPHITE/S-GLASS/NARMCO 5208 HYBRID 2:1 COMPOSITE PANEL

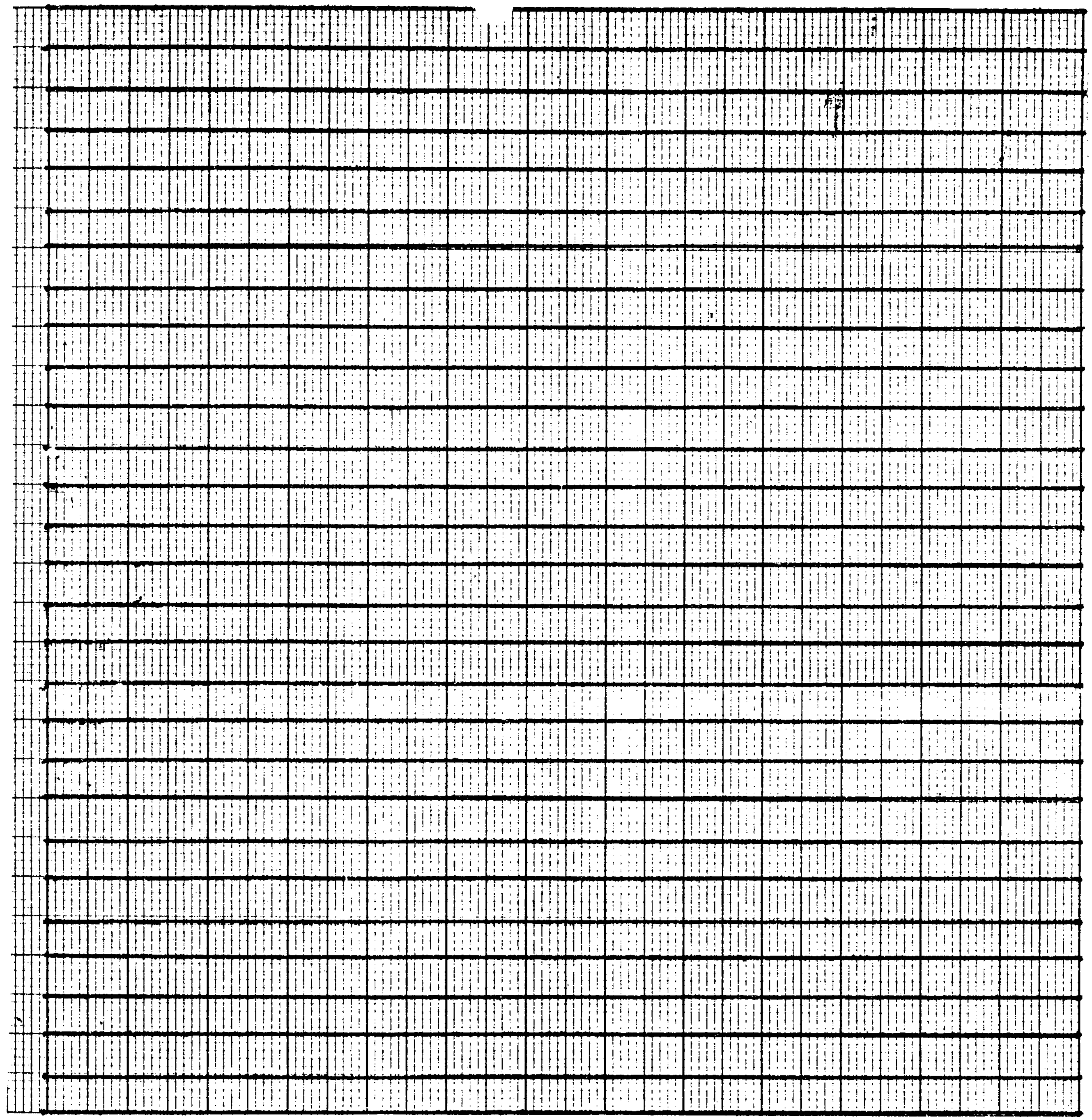


Figure 56 ULTRASONIC C-SCAN FOR ACCEPTABLE $0^{\circ}/90^{\circ}$ T300 GRAPHITE/
S-GLASS HYBRID COMPOSITE PANEL

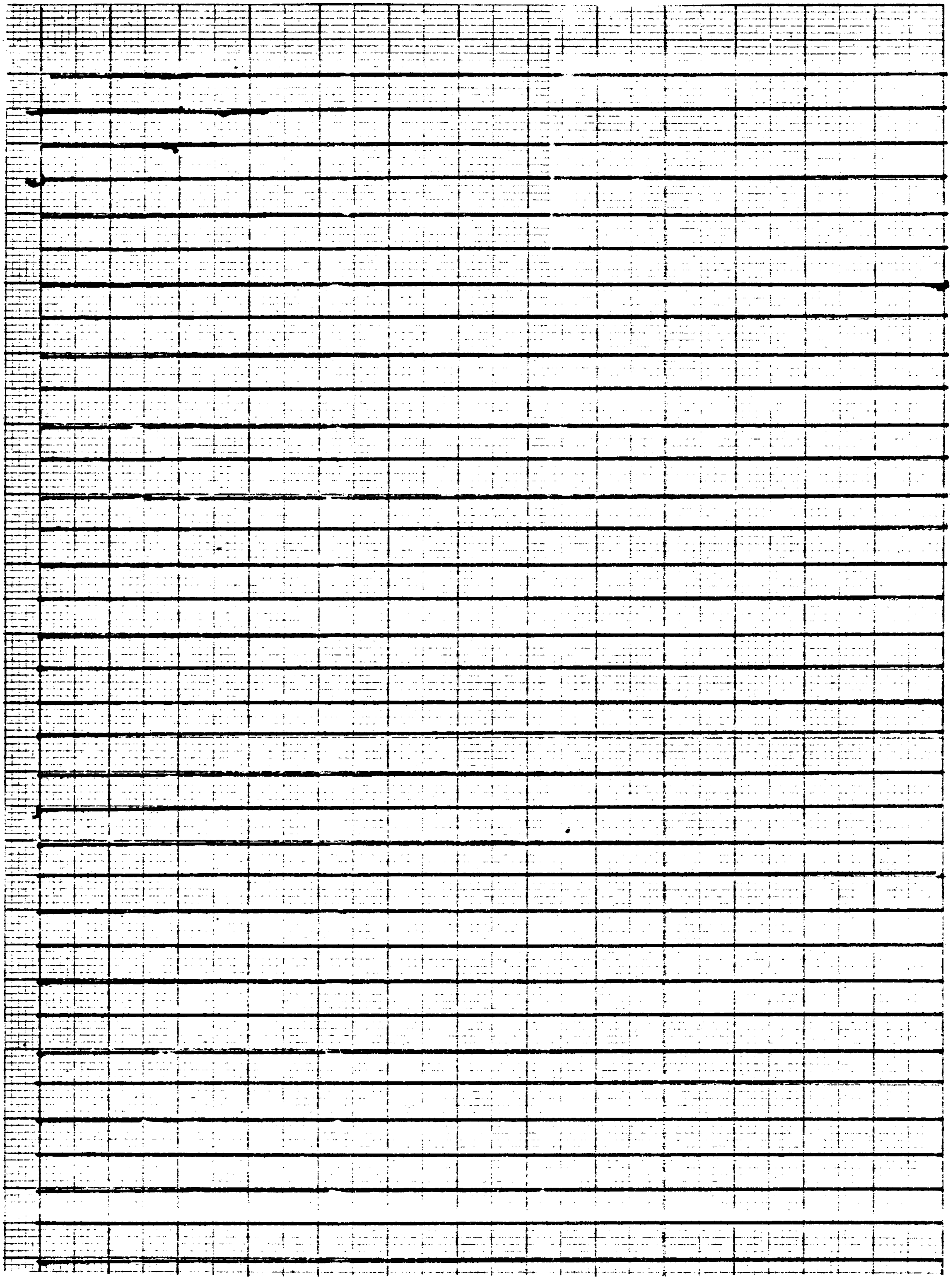


Figure 57 ULTRASONIC C-SCAN FOR ACCEPTABLE $0^{\circ}/90^{\circ}/\pm45^{\circ}$ T300 GRAPHITE/S-GLASS/NARMCO 5208 HYBRID 3:1 COMPOSITE PANEL

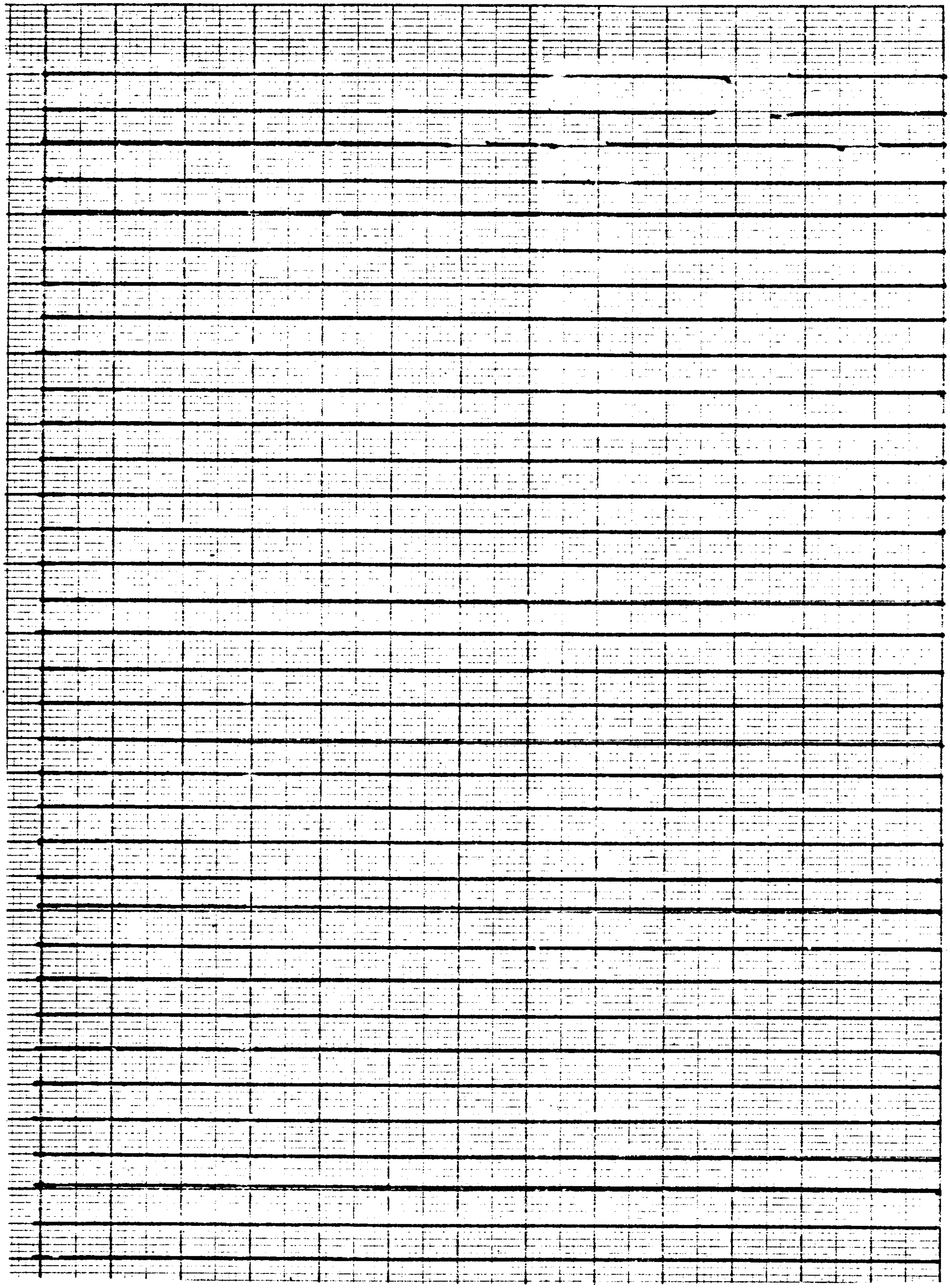


Figure 58 ULTRASONIC C-SCAN FOR UNACCEPTABLE 8 PLY 0° S-GLASS/NARMCO 5208 COMPOSITE PANEL

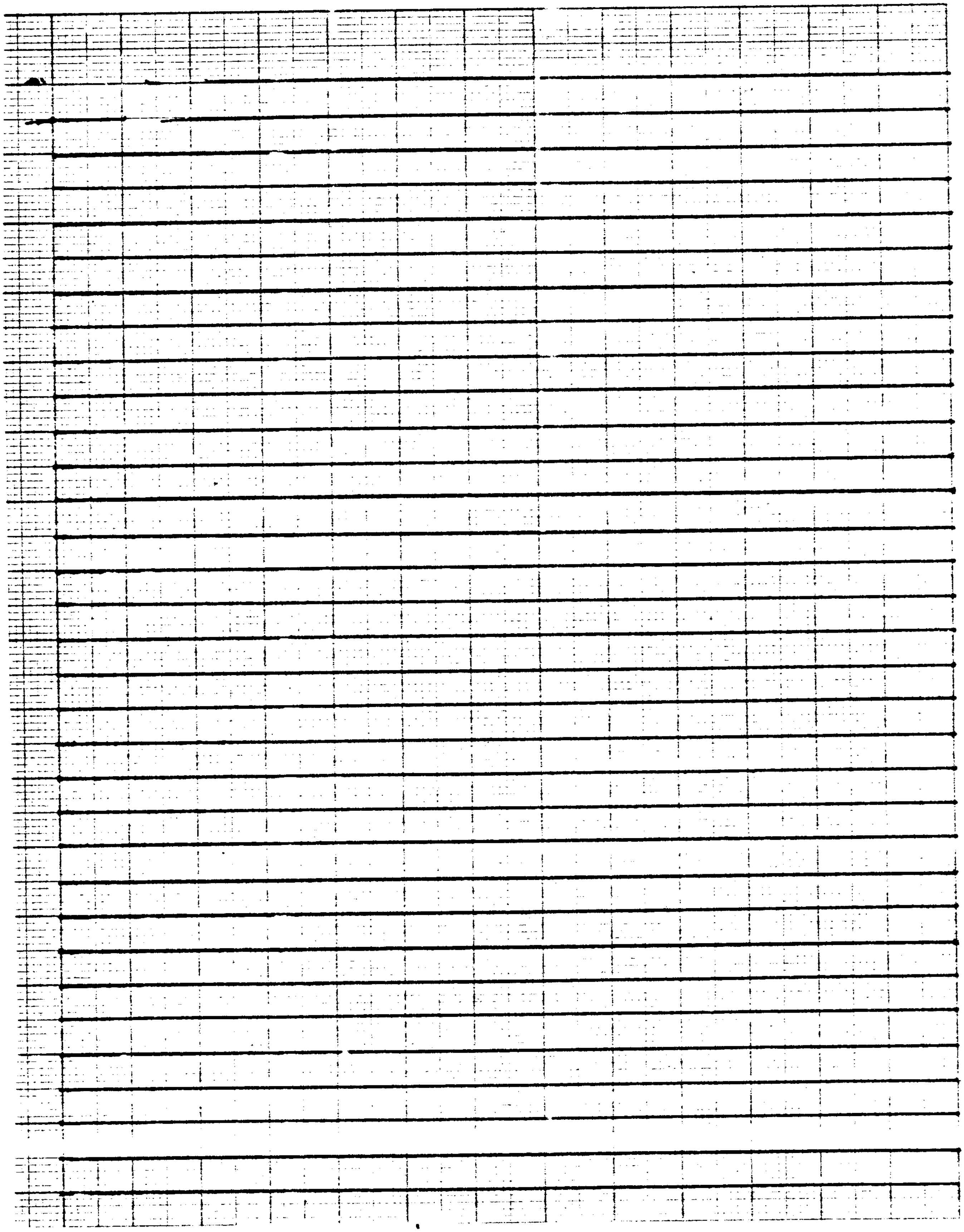


Figure 59 ULTRASONIC C-SCAN FOR UNACCEPTABLE 90° T300 GRAPHITE/S-GLASS/NARMCO 5208 HYBRID 2:1 COMPOSITE PANEL

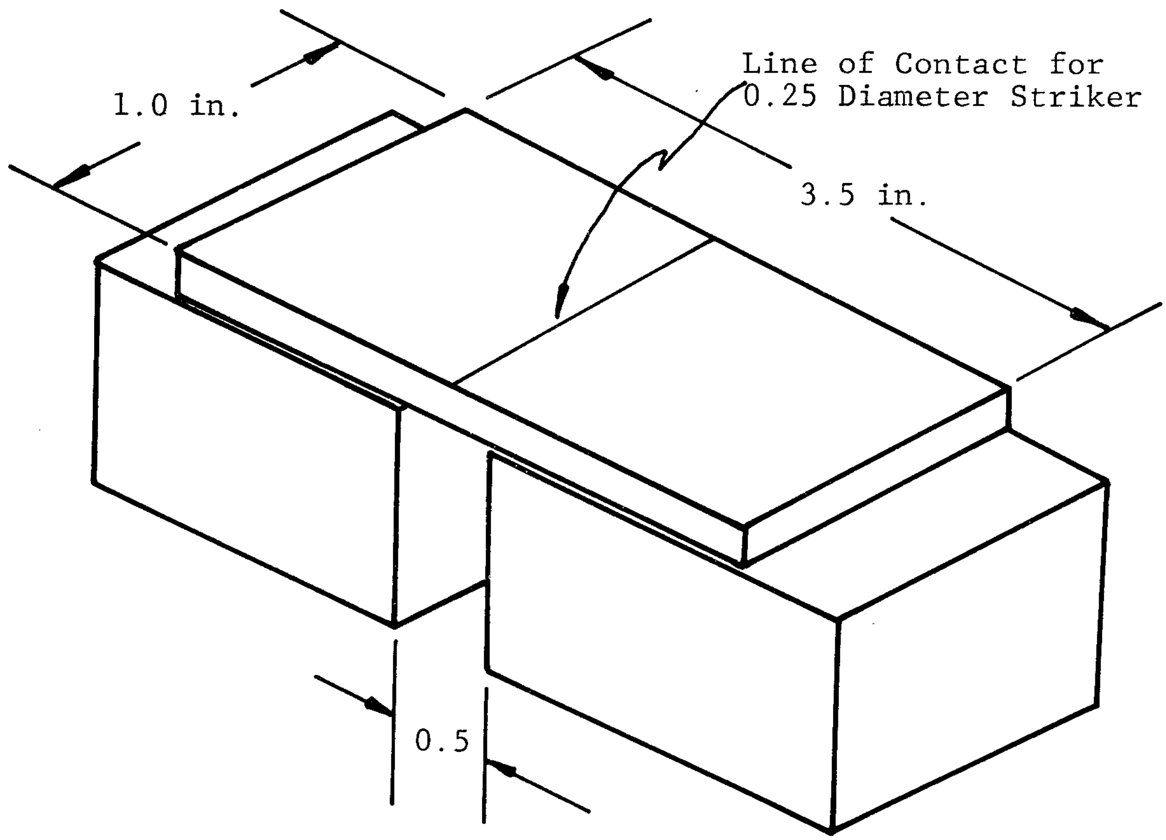


Figure 60 Impact Test Specimen and Support Geometrics.

The principal* mechanical properties for the S-Glass/Narmco 5208, the T-300 Graphite/Narmco 5208 and the S-Glass/T-300 Graphite/Narmco 5208 Hybrid composites are shown in Table VII. They are used frequently as the reference baseline data in the subsequent fatique, residual strength and impact studies. These properties are well characterized and were taken from the literature in an effort to concentrate more thoroughly on the major objectives of this current program.

*The principal mechanical properties include those properties of the basic lamina parallel to and transverse to the fiber direction.

TABLE VII PRINCIPAL PROPERTIES OF T-300 GRAPHITE AND S-GLASS REINFORCED NARMCO 5208 EPOXY COMPOSITES

Material/ Orientation	Property	Temp. ($^{\circ}F$)	Strength (ksi)	Elastic Modules (msi)	Poisson's Ratio (in/in)	Reference *
T300/0°	Tension	70°F 260°F 350°F	218 214 208	26.3 29.8 28.5	0.28 0.31 0.26	Ref. 1 Ref. 1 Ref. 1
	Compression	70°F 260°F 350°F	218 208 206	23.0 21.7 22.5	0.34 0.30 0.31	Ref. 1 Ref. 1 Ref. 1
T300/90°	Tension	70°F 260°F 350°F	5.85 4.11 2.89	1.50 1.68 1.78	0.01 0.01 0.01	Ref. 1 Ref. 1 Ref. 1
	Compression	70°F	36.3 32.6 30.4	1.64 1.68 1.60	0.01 0.01 0.01	Ref. 1 Ref. 1 Ref. 1
S-Glass/0°	Tension	70°F	260	8.8	0.23	Ref. 3
	Compression	70°F	119	--	--	Ref. 2
S-Glass/90°	Tension	70 F	6.7	3.6	0.09	Ref. 2
	Compression	70°F	25.3	--	--	Ref. 2

*See Bibliography at end of Report.

APPENDIX II

INDIVIDUAL FATIGUE TEST RESULTS AND S-N CURVES

Appendix II INDIVIDUAL FATIGUE TEST RESULTS AND S-N CURVES

This appendix presents the data for the basic and hybrid composites. It is restricted to the basic S-N curves and individual fatigue coupon cycle information. The next appendix presents the results of the individual specimen utilized in the residual strength and residual mechanical properties test determinations.

Table VIII shows the individual specimen by specimen test results. It includes specimen thickness on a ply basis and in mils, fiber orientation, prior conditioning (type and duration), moisture weight gain as appropriate, cyclic stress level and cycles to failure or at runout and the residual strength of all runouts as appropriate. Figures 61 through II-97 present the maximum tensile stress per cycle versus cycles to failure curves for all materials as they were generated on this program.

The generally accepted fatigue behavior of glass-epoxy composites is exemplified by the curves shown in Figure 61. The S-N curve begins high at or near the static ultimate strength of the composite but curves rapidly in semilogarithmic plot as the lower stress levels are attained. The stress level at 10^7 cycles is low but the individual data generally are close to the average fatigue behavior of the composite material. The S-N fatigue behavior of the T300 graphite/Narmco 5208 is seen in Figure 63. The shape of the curve is flat and again most data fall rather close to the average curve. On the other hand, the body of data for the hybrid materials exhibits neither perfectly flat behavior nor deep curvature. The data as a whole may not lie close to the average S-N curve for the material. Examined in more detail it is seen that the bottom envelope of the data is curved and the variable data scatter is relatively confined to a short segment of the cycles to failure range.

This behavior is indicative of a mixture of failure modes. Early failure of the glass phase of the hybrid places the burden of load-carrying capacity on the graphite phase which is unable

to sustain the increased load and hence failure of the graphite phase ensues, thus leading to the data on the lower portion of the curves shown in Figures 76 - 97. Thus the mixed mode of failure of the hybrids should produce a larger variability in the cyclic lives at a given stress level.

Table VIII TENSILE FATIGUE TEST RESULTS FOR VARIOUS BASELINE AND HYBRID COMPOSITES (T300 GRAPHITE/NARMCO 5208 AND S-GLASS/5208) HEATED AT ROOM TEMPERATURE AFTER A VARIETY OF CONDITIONING TREATMENTS (R=0.1, ϕ=1800 cpm)

Specimen Number	Thickness (Plies)/ (In.)	MATERIAL AND ORIENTATION	Prior Conditioning TYPE	Prior Conditioning DURATION	Moisture Weight Gain %	Stress Level (ksi)	Cycles to Failure (cycles)	Cycles Applied Without Failure (cycles)	Residual Strength (ksi)	Comment
LO-1	6 / 0.003	$[0^oL]_6$	None	-	-	70	18,000	-	-	Tab Failure
2	6 / 0.033				-	75	18,000	-	-	-
3	6 / 0.033				-	80	15,000	-	-	-
4	6 / 0.032				-	85	9,000	-	-	-
5	6 / 0.032				-	90	7,000	-	-	-
6	6 / 0.033				-	70	24,000	-	-	-
7	6 / 0.032				-	60	58,000	-	-	-
8	6 / 0.033				-	50	112,000	-	-	-
9	6 / 0.033				-	40	394,000	-	-	-
LO-11	6 / 0.033	$[0^oL]_6$	98% RH	500 Hrs.	0.56	60	136,000	-	-	-
12	6 / 0.032				0.44	50	543,000	-	-	-
13	6 / 0.032				0.12	90	7,000	-	-	Tab Failure
14	6 / 0.033				0.57	70	28,000	-	-	Tab Failure
15	6 / 0.033				0.67	40	1,594,000	-	-	Tab Failure
LO-16	6 / 0.034	$[0^oL]_6$	98% RH	1000 Hrs.	1.05	60	247,000	-		Tab Failure
17	6 / 0.034				1.00	50	442,000	-		Tab Failure
18	6 / 0.035				0.89	80	11,000	-		Tab Failure
19	6 / 0.033				1.02	70	32,000	-		Tab Failure
20	6 / 0.033				0.95	40	-	2,000,000	194.8	-
LO-21	6 / 0.032	$[0^oL]_6$	Thermo Humidity Cycle		0.65	80	47,000	-	-	Tab Failure
22	6 / 0.032				0.39	70	376,000	-	-	Tab Failure
23	6 / 0.033				0.63	90	41,000	-	-	Tab Failure
24	6 / 0.035				0.35	100	14,000	-	-	Tab Failure
25	6 / 0.034				0.39	60	388,000	-	-	Tab Failure

Table VIII TENSILE FATIGUE TEST RESULTS FOR VARIOUS BASELINE AND HYBRID COMPOSITES (T300 GRAPHITE/WARMCO 5208 AND S-GLASS/5208) HEATED AT ROOM TEMPERATURE AFTER A VARIETY OF CONDITIONIING TREATMENTS (R=0.1, ϕ=1800 cpm)

Specimen Number	Thickness (Plies)/ (In.)	MATERIAL AND ORIENTATION	Prior Conditioning TYPE	Prior Conditioning DURATION	Moisture Weight Gain %	Stress Level (ksi)	Cycles to Failure (cycles)	Cycles Applied Without Failure (cycles)	Residual Strength (ksi)	Comment
L90-1	8 / 0.043	90^oL_8	None	-	-	4.0	-	2,400,000	8.73	-
2	8 / 0.043				-	5.0	-	2,087,000	8.9	-
3	8 / 0.044				-	7.0	2,000	-	-	-
4	8 / 0.042				-	6.0	112,000	-	-	-
5	8 / 0.042				-	6.5	175,000	-	-	-
L90-6	8 / 0.047	$[90^oL_8]$	98% RH	500 Hrs.	0.39	7.0	4,000	-	-	-
7	8 / 0.042				0.33	6.0	6,286,000	-	-	-
8	8 / 0.055				0.30	6.5	*	Immediate Failure		
9	8 / 0.056				0.30	6.3	*	Immediate Failure		
10	8 / 0.055				0.29	6.1	*	Immediate Failure		
L90-11	8 / 0.060	$[90^oL_8]$	98% RH	1000 Hrs.	0.73	5.0	*	Immediate Failure		
12	8 / 0.056				0.74	4.0	717,000	-	-	-
13	8 / 0.053				0.69	4.5	202,000	-	-	-
14	8 / 0.056				0.69	5.0	2,000	-	-	-
15	8 / 0.043				0.74	4.7	-	2,275,000	7.31	-
L90-16	8 / 0.041	$90^oL_8]$	Thermo Humidity Cycle		0.12	6.8	2,000			
17	8 / 0.043				0.37	*	Failed During Conditioning			
18	8 / 0.041				0.30	*	Failed During Conditioning			
19	8 / 0.043				0.37	6.0	170,000	-	-	-
20	8 / 0.042				0.33	5.6	-	2,470,000	-	-

Table VIII TENSILE FATIGUE TEST RESULTS FOR VARIOUS BASELINE AND HYBRID COMPOSITES (T300 GRAPHITE/WARMCO 5208 AND S-GLASS/5208) HEATED AT ROOM TEMPERATURE AFTER A VARIETY OF CONDITIONING TREATMENTS ($R=0.1$, $\phi=1800$ cpm)

Specimen Number	Thickness (Plies)/ (In.)	MATERIAL AND ORIENTATION	Prior Conditioning TYPE	Prior Conditioning DURATION	Moisture Weight Gain %	Stress Level (ksi)	Cycles to Failure (cycles)	Cycles Applied Without Failure (cycles)	Residual Strength (ksi)	Comment
LQI-1	8 / 0.044	$[0^oL/\pm45^oL/90^oL_2/$	None	-	-	45	2,000	-	-	
2	8 / 0.045	$\pm45^oL/0^oL]$			-	35	5,000	-	-	
3	8 / 0.045				-	25	15,000	-	-	
4	8 / 0.044				-	15	232,000	-	-	
5	8 / 0.046				-	20	45,000	-	-	
6	8 / 0.045				-	30	7,000	-	-	
7	8 / 0.046				-	21.5	9,000	-	-	
8	8 / 0.046				-	22.5	24,000	-	-	
9	8 / 0.044				-	7.5	124,000	-	-	
10	8 / 0.044				-	13	763,000	-	-	
LQI-11	8 / 0.045	$[0^oL/\pm45^oL/90^oL_2/$	98% RH	500 Hrs.	0.44	30	19,000	-	-	
12	8 / 0.045	$\pm45^oL/0^oL]$			0.61	15	-	2,000,000	58.4	
13	8 / 0.046				0.55	20	354,000	-	-	
14	8 / 0.046				0.58	40	7,000	-	-	Tab Failure
15	8 / 0.046				0.58	25	59,000	-	-	-
LQI-16	8 / 0.045	$[0^oL/\pm45^oL/90^oL_2/$	98% RH	1000 Hrs.	0.86	20	767,000	-	-	-
17	8 / 0.044	$\pm45^oL/0^oL]$			1.03	30	92,000	-	-	-
18	8 / 0.043				0.82	40	12,000	-	-	Tab Failure
19	8 / 0.045				0.83	25	606,000	-	-	-
20	8 / 0.043				1.00	35	55,000	-	-	-
LQI-21	8 / 0.046	$[0^oL/\pm45^oL/90^oL_2/$	Thermo Humidity Cycle		0.50	40	9,000	-	-	
22	8 / 0.043	$\pm45^oL/0^oL]$			0.42	30	92,000	-	-	
23	8 / 0.045				0.37	35	68,000	-	-	Tab Failure
24	8 / 0.044				0.46	25	221,000	-	-	
25	8 / 0.044				0.43	20	966,000	-	-	

Table VIII TENSILE FATIGUE TEST RESULTS FOR VARIOUS BASELINE AND HYBRID COMPOSITES (T300 GRAPHITE/WARMCO 5208 AND S-GLASS/5208) HEATED AT ROOM TEMPERATURE AFTER A VARIETY OF CONDITIONIING TREATMENTS (R=0.1, ϕ=1800 cpm)

Specimen Number	Thickness (Plies)/ (In.)	MATERIAL AND ORIENTATION	Prior Conditioning TYPE	Prior Conditioning DURATION	Moisture Weight Gain %	Stress Level (ksi)	Cycles to Failure (cycles)	Cycles Applied Without Failure (cycles)	Residual Strength (ksi)	Comment
TQI-1	8 /	$[0^{o}R/\pm45^{o}R/90^{o}R_2/$	None	-	-	40	-	4,613,000	55.4	-
2	8 /	$\pm45^{o}R/0^{o}R]$			-	55	*	Immediate Tab Failure		
3	8 /				-	50	-	2,759,000	61.8	-
4	8 /				-	60	4,000	-	-	
5	8 /				-	55	56,000	-	-	
6	8 /				-	52	162,000	-	-	
7	8 /				-	58	9,000	-	-	
8	8 /				-	56.5	14,000	-	-	
9	8 /				-	53.5	38,000	-	-	
10	8 /				-	51	201,000	-	-	
TQI-16	8 / 0.046	$[0^{o}R/\pm45^{o}R/90^{o}R_2/$	98% RH	500 Hrs.	0.52	60	16,000	-	-	-
17	8 / 0.046	$\pm45^{o}R/0^{o}R]$			0.54	58	65,000	-	-	-
18	8 / 0.045				0.52	62	2,000	-	-	-
19	8 / 0.044				0.49	56	138,000	-	-	-
20	8 / 0.042				0.48	54	2,123,000	-	-	-
TQI-11	8 / 0.046	$[0^{o}R/\pm45^{o}R/90^{o}R_2/$	98% RH	1000 Hrs.	0.83	58	33,000	-	-	-
12	8 / 0.046	$\pm45^{o}R/0^{o}R]$			0.81	60	10,000	-	-	-
13	8 / 0.046				0.85	55	97,000	-	-	-
14	8 / 0.046				0.83	53	365,000	-	-	-
15	8 / 0.046				0.85	50	1,421,000	-	-	-
TQI-21	8 / 0.047	$[0^{o}R/\pm45^{o}R/90^{o}R_2/$	Thermo Humidity Cycle		0.69	60	12,000	-	-	-
22	8 / 0.047	$\pm45^{o}R/0^{o}R]$			0.39	55	34,000	-	-	-
23	8 / 0.047				0.76	50	-	2,403,000	-	-
24	8 / 0.047				0.51	58	128,000	-	-	-
25	8 / 0.047				0.68	56	269,000	-	-	-

Table VIII TENSILE FATIGUE TEST RESULTS FOR VARIOUS BASELINE AND HYBRID COMPOSITES (T300 GRAPHITE/WARMCO 5208 AND S-GLASS/5208) HEATED AT ROOM TEMPERATURE AFTER A VARIETY OF CONDITIONING TREATMENTS (R=0.1, ϕ=1800 cpm)

Specimen Number	Thickness (Plies)/ (In.)	MATERIAL AND ORIENTATION	Prior Conditioning TYPE	Prior Conditioning DURATION	Moisture Weight Gain %	Stress Level (ksi)	Cycles to Failure (cycles)	Cycles Applied Without Failure (cycles)	Residual Strength (ksi)	Comment
H20-1	6 /	$[0^oR/0^oL/0^oR_2/$	None	-	-	160	*	Immediate Tab Failure		
2	6 /	$0^oL/0^oR]$			-	135	3,000	-	-	
3	6 /				-	120	23,000	-	-	
4	6 /				-	115	5,000	-	-	
5	6 /				-	110	39,000	-	-	
6	6 /				-	100	-	2,320,000	157.7	
7	6 /				-	105	399,000	-	-	
8	6 /				-	130	2,000	-	-	
9	6 /				-	125	2,000	-	-	
10	6 /				-	110	25,000	-	-	
H20-11	6 / 0.037	$[0^oR/0^oL/0^oR_2/$	98% RH	500 Hrs.	0.54	130	7,000	-	-	
12	6 / 0.035	$0^oL/0^oR]$			0.99	125	8,000	-	-	
13	6 / 0.037				0.53	100	1,199,000	-	-	Tab Failure
14	6 / 0.038				0.82	120	12,000	-	-	
15	6 / 0.036				1.10	110	216,000	-	-	
H20-16	6 / 0.037	$[0^oR/0^oL/0^oR_2/$	98% RH	1000 Hrs.	0.94	125	1,102,000	-	-	-
17	6 / 0.037	$0^oL/0^oR]$			0.98	120	125,000	-	-	-
18	6 / 0.036				0.97	110	249,000	-	-	-
19	6 / 0.036				0.90	130	5,000	-	-	Tab Failure
20	6 / 0.037				0.97	105	-	2,081,000	182.2	-
H20-21	6 / 0.036	$[0^oR/0^oL/0^oR_2/$	Thermo Humidity Cycle		0.57	130	390,000	-	-	Tab Failure
22	6 / 0.036	$0^oL/0^oR]$			0.53	145	276,000	-	-	Tab Failure
23	6 / 0.035				0.62	140	837,000	-	-	Tab Failure
24	6 / 0.037				0.58	150	68,000	-	-	Tab Failure
25	6 / 0.037				0.48	160	4,000	-	-	Tab Failure

Table VIII TENSILE FATIGUE TEST RESULTS FOR VARIOUS BASELINE AND HYBRID COMPOSITES (T300 GRAPHITE/NARMCO 5208 AND S-GLASS/5208) HEATED AT ROOM TEMPERATURE AFTER A VARIETY OF CONDITIONING TREATMENTS (R=0.1, ϕ=1800 cpm)

Specimen Number	Thickness (Plies)/(In.)	MATERIAL AND ORIENTATION	Prior Conditioning TYPE	Prior Conditioning DURATION	Moisture Weight Gain %	Stress Level (ksi)	Cycles to Failure (cycles)	Cycles Applied Without Failure (cycles)	Residual Strength (ksi)	Comment
H01-1	8 / 0.045	$[0^oR/0^oL/0^oR/0^oL_2/$	None	-	-	120	3,000	-	-	
2	8 / 0.045	$0^oR/0^oL/0^oR]$			-	100	8,000	-	-	
3	8 / 0.045				-	90	54,000	-	-	
4	8 / 0.046				-	85	-	2,053,000	124.1	
5	8 / 0.046				-	95	163,000	-	-	
6	8 / 0.045				-	110	36,000	-	-	
7	8 / 0.046				-	105	10,000	-	-	
8	8 / 0.047				-	90	82,000	-	-	
9	8 / 0.047				-	100	13,000	-	-	
10	8 / 0.046				-	87	54,000	-	-	
H01-11	8 / 0.046	$[0^oR/0^oL/0^oR/0^oL_2/$	98% RH	500 Hrs.	0.48	90	-	7,534,000	136.9	Tab Failure
12	8 / 0.045	$0^oR/0^oL/0^oR]$			0.48	100	80,000	-	-	
13	8 / 0.045				-	95	990,000	-	-	Tab Failure
14	8 / 0.045				0.58	120	259,000	-	-	Tab Failure
15	8 / 0.045				0.53	110	15,000	-	-	
H01-16	8 / 0.043	$[0^oR/0^oL/0^oR/0^oL_2/$	98% RH	1000 Hrs.	0.84	100	63,000	-	-	Tab Failure
17	8 / 0.044	$0^oR/0^oL/0^oR]$			0.81	110	18,000	-	-	Tab Failure
18	8 / 0.047				0.83	120	4,000	-	-	Tab Failure
19	8 / 0.047				0.82	95	-	2,347,000	119.5	-
20	8 / 0.046				0.84	97	1,008,000	-	-	Tab Failure
H01-21	8 / 0.047	$[0^oR/0^oL/0^oR/0^oL_2/$	Thermo Humidity Cycle		0.51	110	35,000	-	-	Tab Failure
22	8 / 0.047	$0^oR/0^oL/0^oR]$			0.45	130	6,000	-	-	Tab Failure
23	8 / 0.046				0.52	120	236,000	-	-	Tab Failure
24	8 / 0.046				0.42	125	24,000	-	-	Tab Failure
25	8 / 0.045				0.55	115	2,342,000	-	-	Tab Failure

Table VIII TENSILE FATIGUE TEST RESULTS FOR VARIOUS BASELINE AND HYBRID COMPOSITES (T300 GRAPHITE/WARMCO 5208 AND S-GLASS/5208) HEATED AT ROOM TEMPERATURE AFTER A VARIETY OF CONDITIONING TREATMENTS (R=0.1, ϕ=1800 cpm)

Specimen Number	Thickness (Plies)/ (In.)	MATERIAL AND ORIENTATION	Prior Conditioning TYPE	Prior Conditioning DURATION	Moisture Weight Gain %	Stress Level (ksi)	Cycles to Failure (cycles)	Cycles Applied Without Failure (cycles)	Residual Strength (ksi)	Comment
H91-1	8 / 0.050	$[90^oR/90^oL/90^oR/90^oL_2/$ $90^oR/90^oL/90^oR]$	None	-	-	7.0	Immediate Failure			
2	8 / 0.049				-	5.0	114,000	-	-	-
3	8 / 0.050				-	6.0	1,000	-	-	-
4	8 / 0.050				-	4.0	-	7,074,000	6.61	-
5	8 / 0.048				-	5.5	Failed During Installation			
H91-6	8 / 0.049	$[90^oR/90^oL/90^oR/90^oL_2/$ $90^oR/90^oL/90^oR]$	98% RH	1000 Hrs.	0.82	4.8	31,000	-	-	-
7	8 / 0.045				0.86	4.4	29,000	-	-	-
8	8 / 0.050				0.77	4.0	529,000	-	-	-
H92-1	9 / 0.053	$[90^oR/90^oL/90^oR_2/90^oL/$ $90^oR_2/90^oL/90^oR$	None	-	-	6.0	Immediate Failure			
2	9 / 0.053				-	5.0	1,000	-	-	-
3	9 / 0.053				-	4.0	-	2,494,000	7.01	-
4	9 / 0.052				-	4.5	22,000	-	-	-
5	9 / 0.053				-	4.3	-	2,677,000	6.66	-
H92-6	9 / 0.053	$[90^oR/90^oL/90^oR_2/90^oL/$ $90^oR_2/90^oL/90^oR$	98% RH	1000 Hrs.	0.71	5.0	1,000	-	-	-
7	9 / 0.053				0.66	4.5	491,000	-	-	-
8	9 / 0.053				0.64	4.7	5,000	-	-	-

Table VIII TENSILE FATIGUE TEST RESULTS FOR VARIOUS BASELINE AND HYBRID COMPOSITES (T300 GRAPHITE/NARMCO 5208 AND S-GLASS/5208) HEATED AT ROOM TEMPERATURE AFTER A VARIETY OF CONDITIONING TREATMENTS ($R=0.1$, $\phi=1800$ cpm)

Specimen Number	Thickness (Plies)/ (In.)	MATERIAL AND ORIENTATION	Prior Conditioning TYPE	Prior Conditioning DURATION	Moisture Weight Gain %	Stress Level (ksi)	Cycles to Failure (cycles)	Cycles Applied Without Failure (cycles)	Residual Strength (ksi)	Comment
HQ1-1	8 /	$[0^oR/\pm45^oL/90^oR_2/\pm45^oL/0^oR]$	None	-	-	60	1,000	-	-	-
2	8 /				-	45	-	7,109,000	62.4	-
3	8 /				-	55	99,000	-	-	
4	8 /				-	60	4,000	-	-	
5	8 /				-	50	696,000	-	-	
6	8 /				-	58	25,000	-	-	
7	8 /				-	56	45,000	-	-	
8	8 /				-	53	122,000	-	-	
9	8 /				-	52	59,000	-	-	
10	8 /				-	48	1,514,000	-	-	
HQ1-11	8 / 0.046	$[0^oR/\pm45^oL/90^oR_2/\pm45^oL/0^oR]$	98% RH	1000 Hrs.	0.72	60	2,000	-	-	
12	8 / 0.047				0.77	50	-	2,554,000	72.0	
13	8 / 0.047				0.77	58	11,000	-	-	
14	8 / 0.047				1.08	55	99,000	-	-	
15	8 / 0.046				0.81	53	1,993,000	-	-	

Table VIII TENSILE FATIGUE TEST RESULTS FOR VARIOUS BASELINE AND HYBRID COMPOSITES (T300 GRAPHITE/WARMCO 5208 AND S-GLASS/5208) HEATED AT ROOM TEMPERATURE AFTER A VARIETY OF CONDITIONING TREATMENTS ($R=0.1$, $\phi=1800$ cpm)

Specimen Number	Thickness (Plies)/ (In.)	MATERIAL AND ORIENTATION	Prior Conditioning TYPE	Prior Conditioning DURATION	Moisture Weight Gain %	Stress Level (ksi)	Cycles to Failure (cycles)	Cycles Applied Without Failure (cycles)	Residual Strength (ksi)	Comment
HQ2-1	12 /	$[0^oR/90^oR/\pm45^oL/90^oR/0^oR_2/90^oR/\mp45^oL/90^oR/0^oR]$	None	-	-	55	1,698,000	-	-	-
2	12 /				-	70	1,000	-	-	-
3	12 /				-	65	2,000	-	-	-
4	12 /				-	60	392,000	-	-	-
5	12 /				-	65	1,000	-	-	-
6	12 /				-	63	2,000	-	-	-
7	12 /				-	61	11,000	-	-	-
8	12 /				-	62	4,000	-	-	-
9	12 /				-	58	3,819,000	-	-	-
10	12 /				-	59	93,000	-	-	-
HQ2-11	12 / 0.068	$[0^oR/90^oR/\pm45^oL/90^oR/0^oR_2/90^oR/\mp45^oL/90^oR/0^oR]$	98% RH	1000 Hrs.	0.60	60	2,500,000	-	-	Tab Failure
12	12 / 0.069				0.64	70	Immediate Tab Failure			
13	12 / 0.069				0.62	65	2,873,000	-	-	-
14	12 / 0.067				0.65	72	1,000	-	-	Tab Failure
15	12 / 0.070				0.64	70	35,000	-	-	-

Table VIII TENSILE FATIGUE TEST RESULTS FOR VARIOUS BASELINE AND HYBRID COMPOSITES (T300 GRAPHITE/NARMCO 5208 AND S-GLASS/5208) TESTED AT ROOM TEMPERATURE AFTER A VARIETY OF CONDITIONING TREATMENTS ($R=0.1$, $\phi=1800$ cpm)

Specimen Number	Thickness (Plies)/ (In.)	MATERIAL AND ORIENTATION	Prior Conditioning TYPE	Prior Conditioning DURATION	Moisture Weight Gain %	Stress Level (ksi)	Cycles to Failure (cycles)	Cycles Applied Without Failure (cycles)	Residual Strength (ksi)	Comment
H03-1	8 / 0.043	$[0^oR/0^oL/0^oR_4/$	None	-	-	120	4,000	-	-	
2	8 / 0.043	$0^oL/0^oR]$			-	110	9,000	-	-	
3	8 / 0.043				-	100	57,000	-	-	
4	8 / 0.045				-	90	135,000	-	-	
5	8 / 0.044				-	80	765,000	-	-	
6	8 / 0.043				-	85	-	2,468,000	116.9	
7	8 / 0.044				-	105	10,000	-	-	
8	8 / 0.042				-	95	-	2,434,000	169.0	
9	8 / 0.043				-	97	15,000	-	-	
10	8 / 0.043				-	105	5,000	-	-	
H03-11	8 / 0.043	$[0^oR/0^oL/0^oR_4/$	98% RH	500 Hrs.	0.51	110	1,131,000	-	-	
12	8 / 0.044	$0^oL/0^oR]$			0.51	130	65,000	-	-	
13	8 / 0.046				-	120	120,000	-	-	
14	8 / 0.045				0.47	140	3,000	-	-	
15	8 / 0.045				0.53	135	4,000	-	-	
H03-16	8 / 0.043	$[0^oR/0^oL/0^oR_4/$	98% RH	1000 Hrs.	1.00	135	5,000	-	-	
17	8 / 0.044	$0^oL/0^oR]$			1.06	130	7,000	-	-	
18	8 / 0.045				0.90	120	97,000	-	-	
19	8 / 0.047				0.94	127	7,000	-	-	
20	8 / 0.042				0.97	125	-	2,380,000	166.1	-
H03-21	8 / 0.044	$[0^oR/0^oL/0^oR_4/$	Thermo Humidity Cycle		0.54	140	3,000	-	-	Tab Failure
22	8 / 0.042	$0^oL/0^oR]$			0.50	130	41,000	-	-	
23	8 / 0.043				0.49	150	13,000	-	-	
24	8 / 0.044				0.52	120	-	2,113,000	151.3	-
25	8 / 0.043				0.60	125	315,000	-	-	Tab Failure

Table VIII TENSILE FATIGUE TEST RESULTS FOR VARIOUS BASELINE AND HYBRID COMPOSITES (T300 GRAPHITE/WARMCO 5208 AND S-GLASS/5208) HEATED AT ROOM TEMPERATURE AFTER A VARIETY OF CONDITIONING TREATMENTS ($R=0.1$, $\phi=1800$ cpm)

Specimen Number	Thickness (Plies) / (In.)	MATERIAL AND ORIENTATION	Prior Conditioning TYPE	Prior Conditioning DURATION	Moisture Weight Gain %	Stress Level (ksi)	Cycles to Failure (cycles)	Cycles Applied Without Failure (cycles)	Residual Strength (ksi)	Comment
HQ3-1	16 /	[$0^oR/90^oR/0^oR/90^oR/$	None	-	-	60	3,000	-	-	-
2	16 /	$\pm45^oL/90^oR/0^oR_2/90^oR/$			-	50	-	2,090,000	83.7	-
3	16 /	$\mp45^oL/90^oR/0^oR/$			-	55	1,141,000	-	-	-
4	16 /	$90^oR/0^oR$			-	58	-	5,430,000	84.5	-
5	16 /				-	60	-	2,500,000	84.5	-
6	16 /				-	65	6,000	-	-	-
7	16 /				-	63	-	2,675,000	83.1	-
8	16 /				-	64	1,771,000	-	-	-
9	16 /				-	66	32,000	-	-	-
10	16 /				-	68	3,000	-	-	-
HQ3-11	16 / 0.096	$0^oR/90^oR/0^oR/90^oR/$	98% RH	1000 Hrs.	0.69	70	1,000	-	-	Tab Failure
12	16 / 0.096	$\pm45^oL/90^oR/0^oR_2/90^oR/$			0.72	65	-	10,098,000	82.6	-
13	16 / 0.095	$\mp45^oL/90^oR/0^oR/$			0.68	68	2,077,000	-	-	Tab Failure
14	16 / 0.095	$90^oR/0^oR$			0.72	73	1,000	-	-	-
15	16 / 0.099				0.73	71	72,000	-	-	-

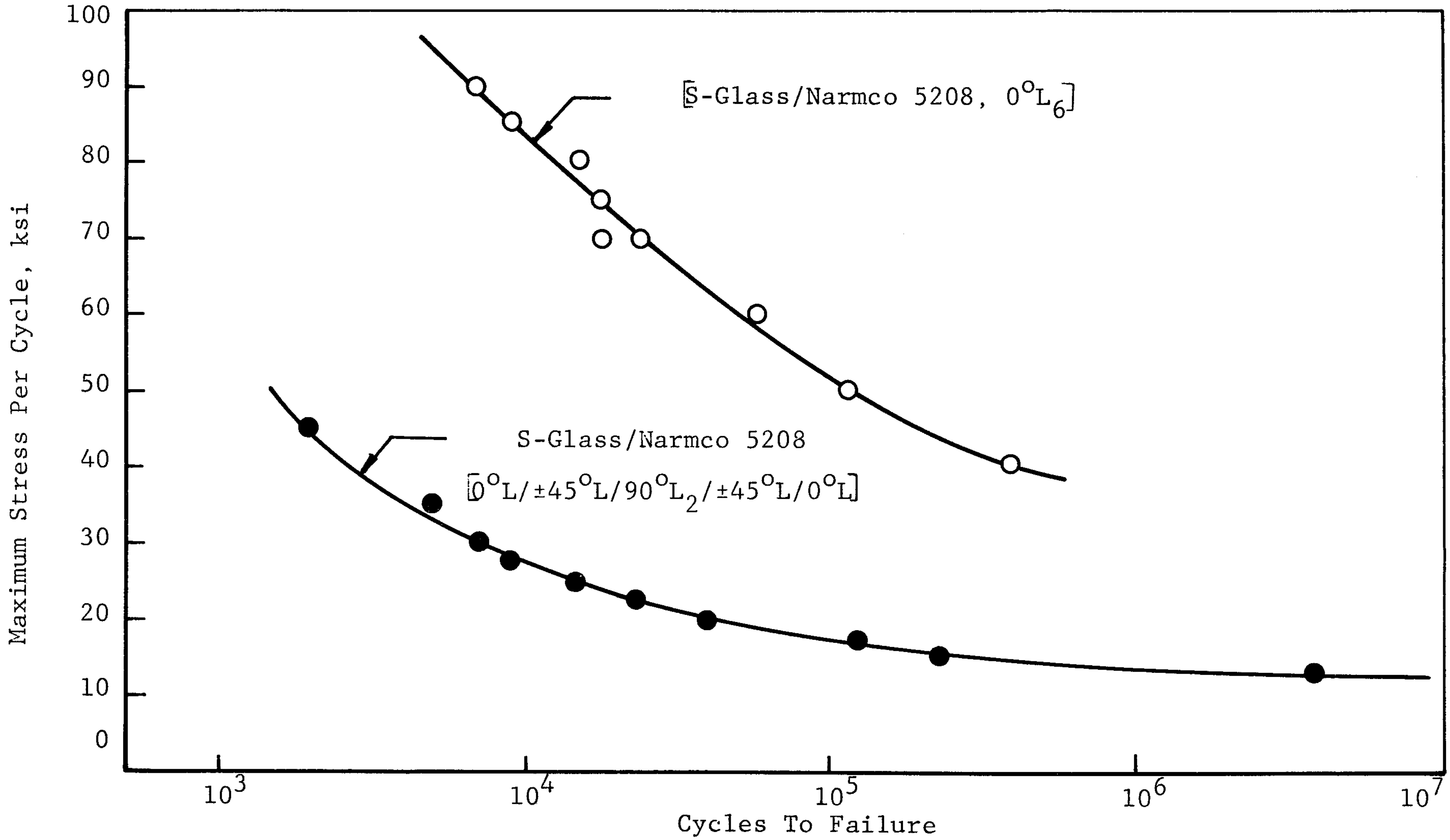


Fig. 61 Fatigue S-N Curve For S-Glass/Narmco 5208 Composites Tested at R=0.1, ϕ=30 Hertz, and T=70^{o}F

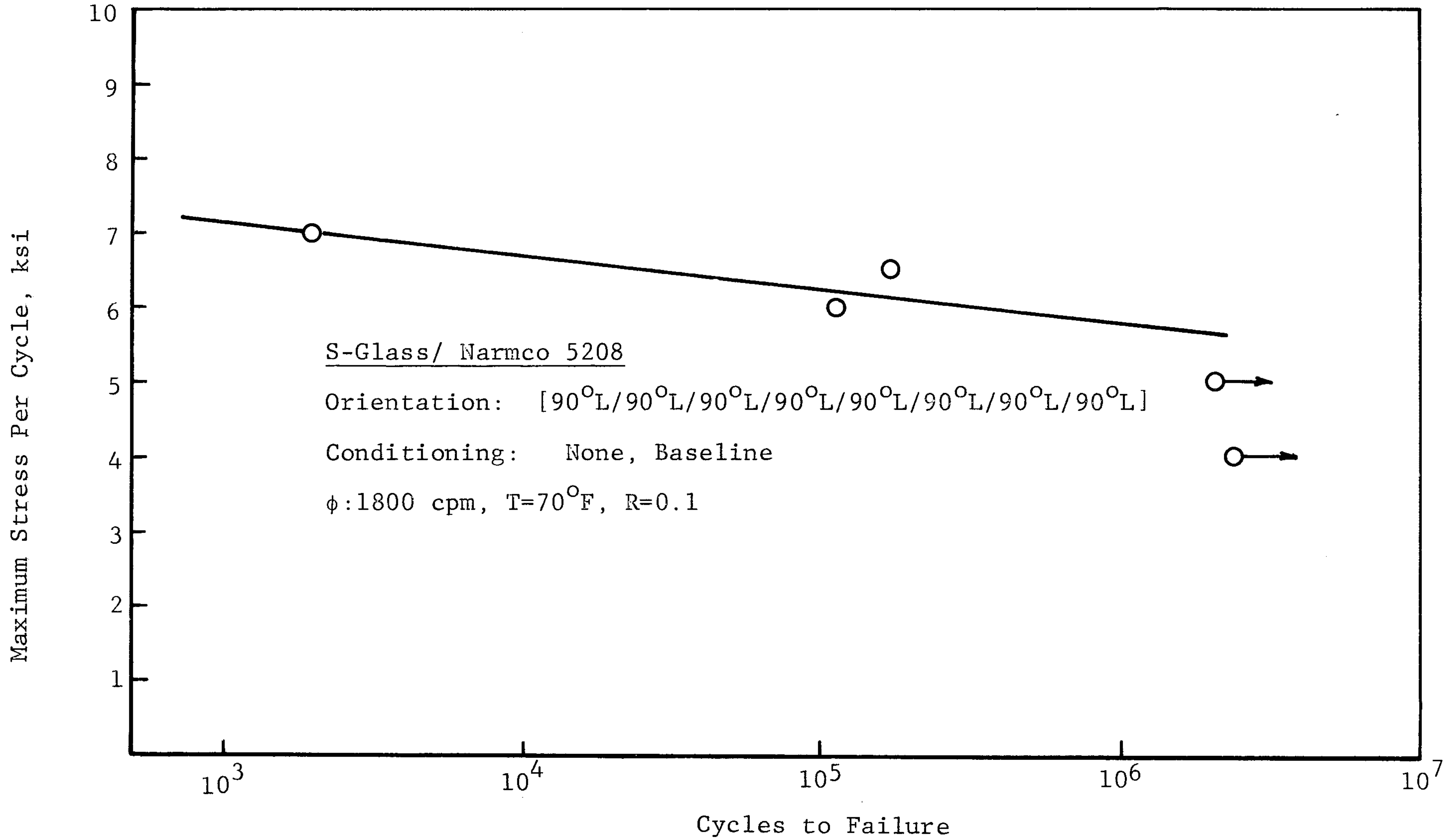


Figure 62 Fatigue S-N Curve For S-Glass/Narmco 5208 Composite, Tested at R = 0.1, ϕ = 30 Hertz, and T = 70°F.

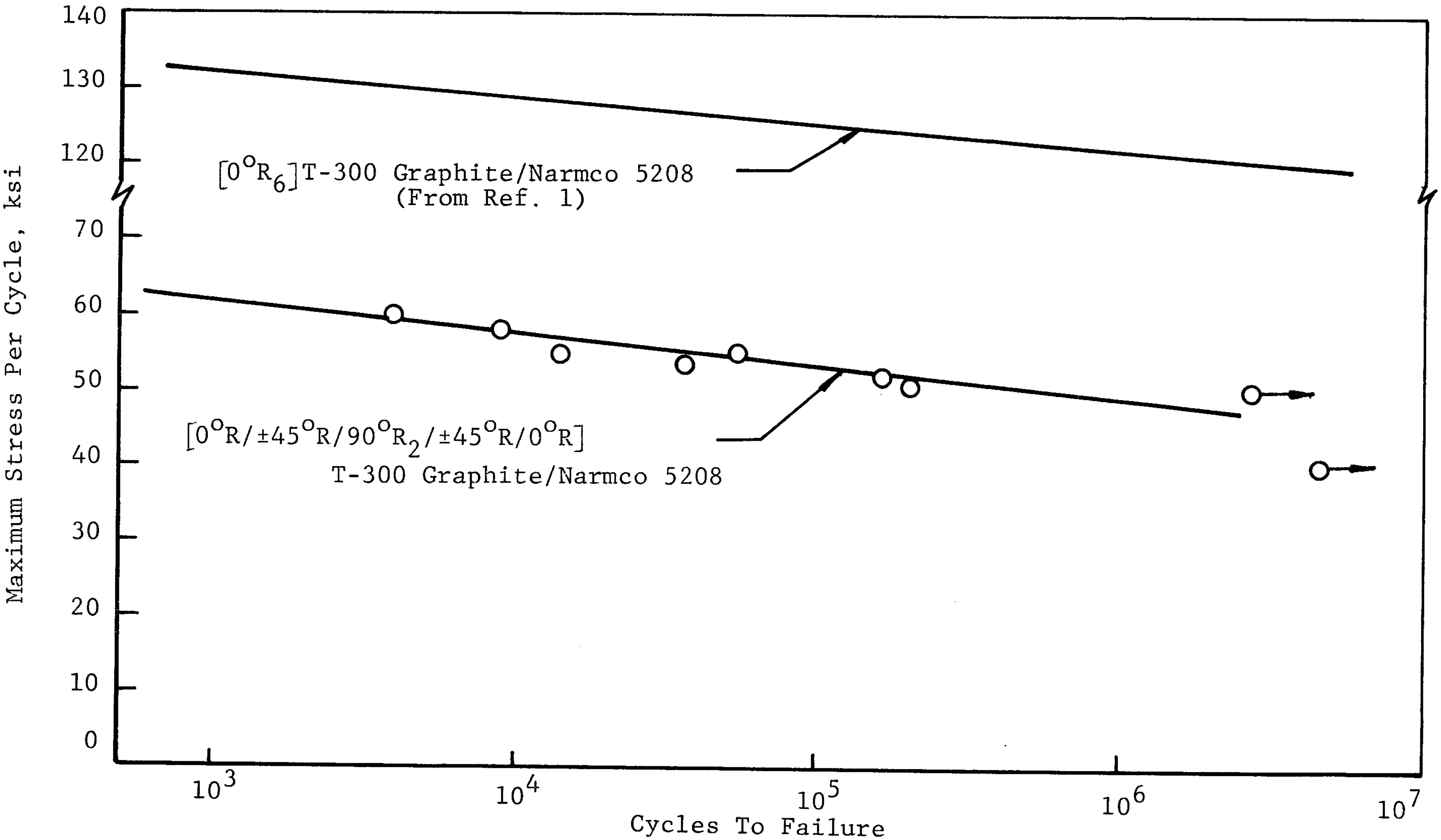


Fig. 63 Fatigue S-N Curve For T-300 Graphite/Narmco 5208 Composites Tested at R=0.1, ϕ=30 Hertz, and T=70^{o}F

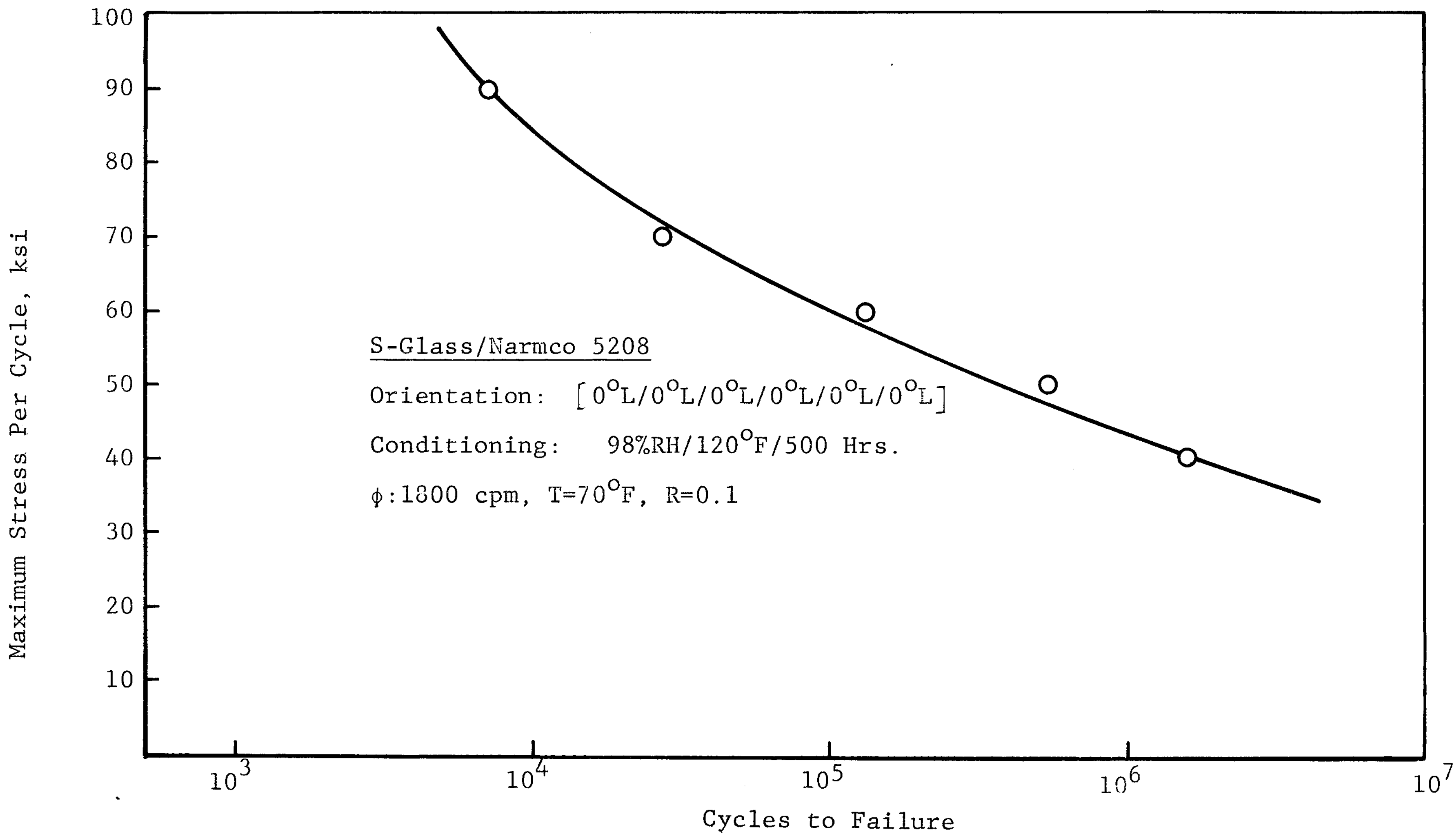


Figure 64 Fatigue S-N Curve for S-Glass/Narmco 5208 Composite, Tested at $R = 0.1$, $\phi = 30$ Hertz, and $T = 70^{o}F$ After Conditioning at 98% RH, and $120^{o}F$ for 500 Hours

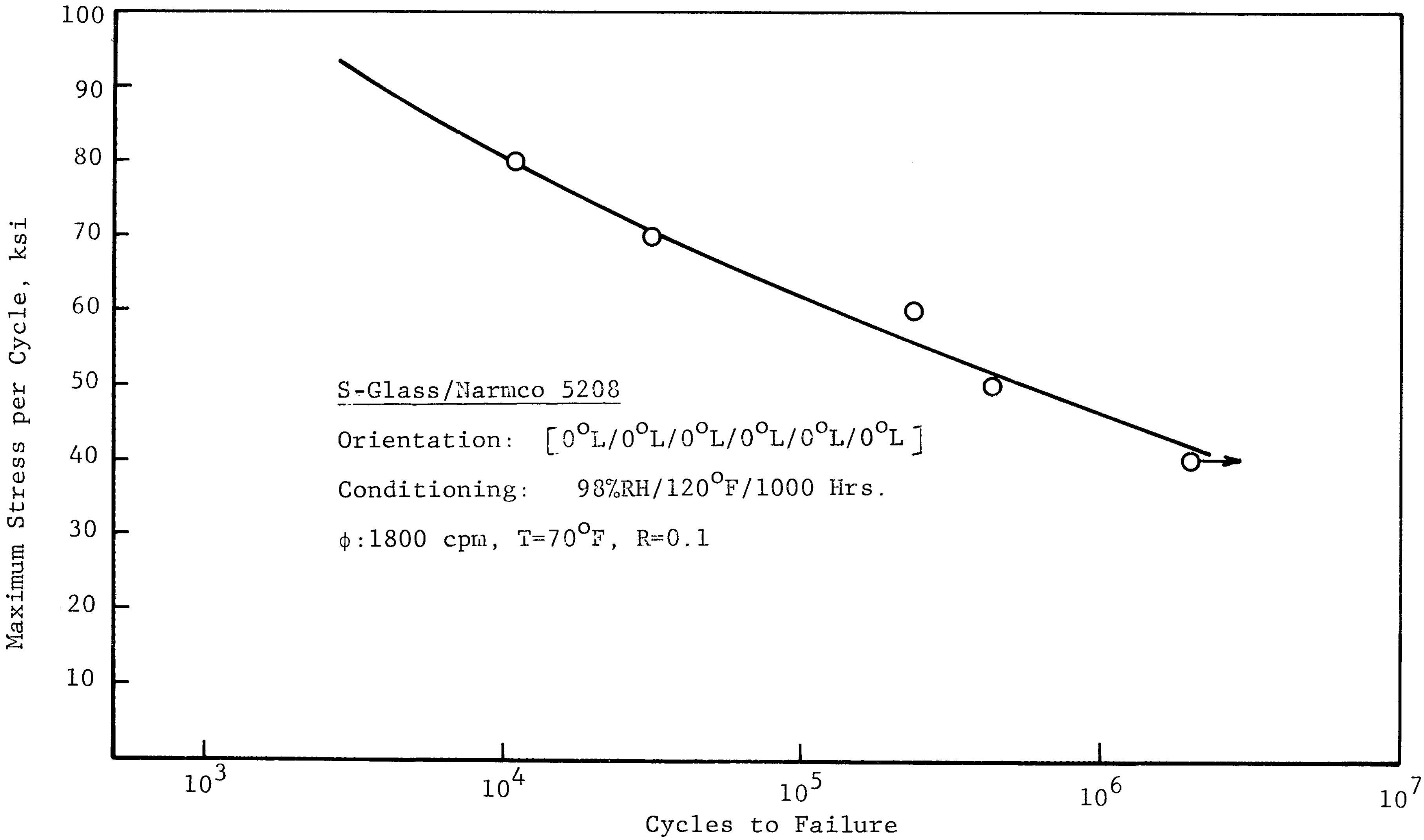


Figure 65 Fatigue S-N Curve For S-Glass/Narmco 5208 Composite, Tested at R = 0.1, ϕ = 30 Hertz, and T = 70^{o}F After Conditioning at 98% RH, and 120^{o}F for 1,000 Hours.

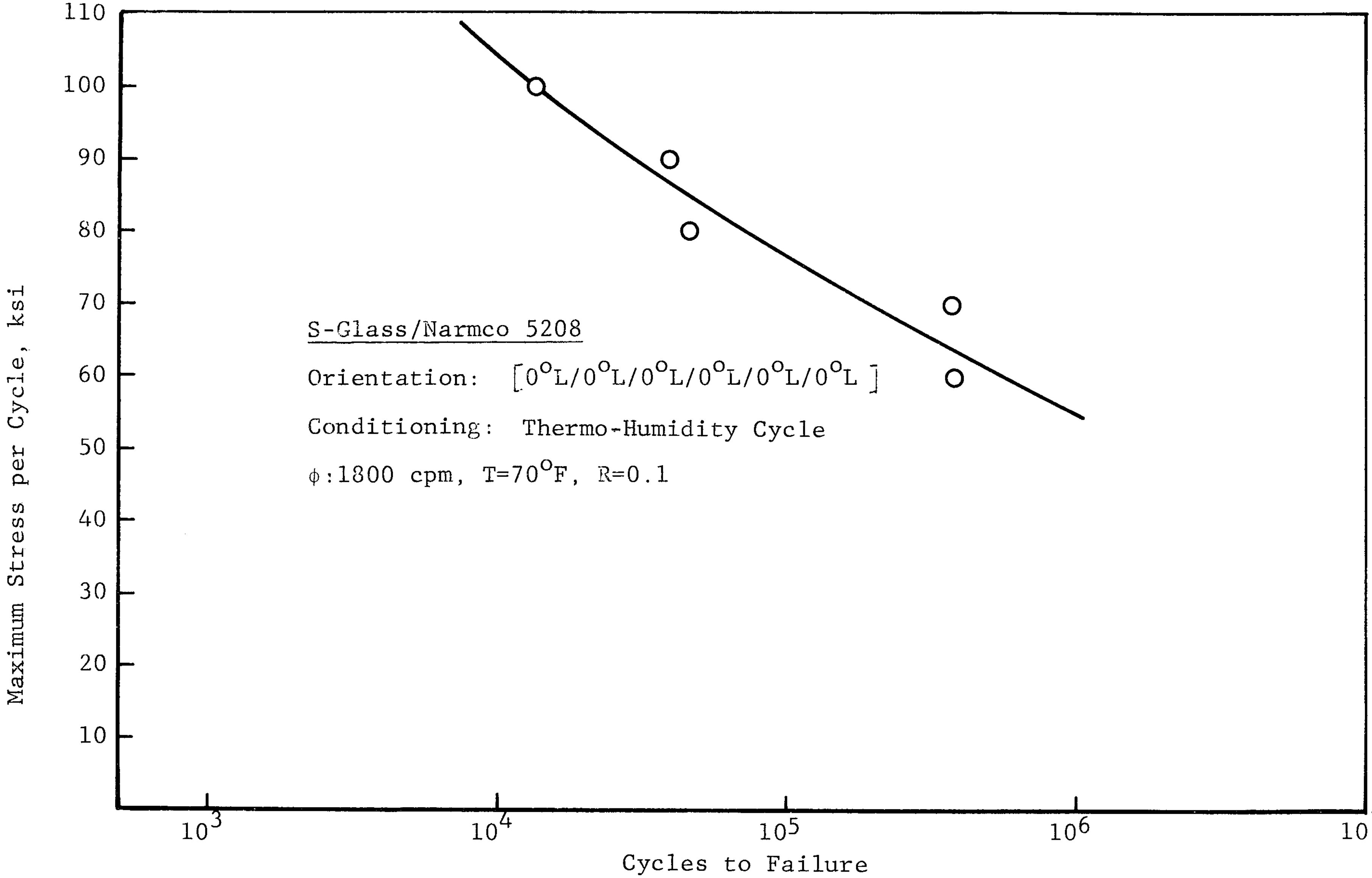


Figure 66 FAtigue S-N Curve For S-Glass/Narmco 5208 Composite, Tested at R = 0.1, ϕ = 30 Hertz, and T = 70°F After Thermo-Humidity Cyclic Conditioning.

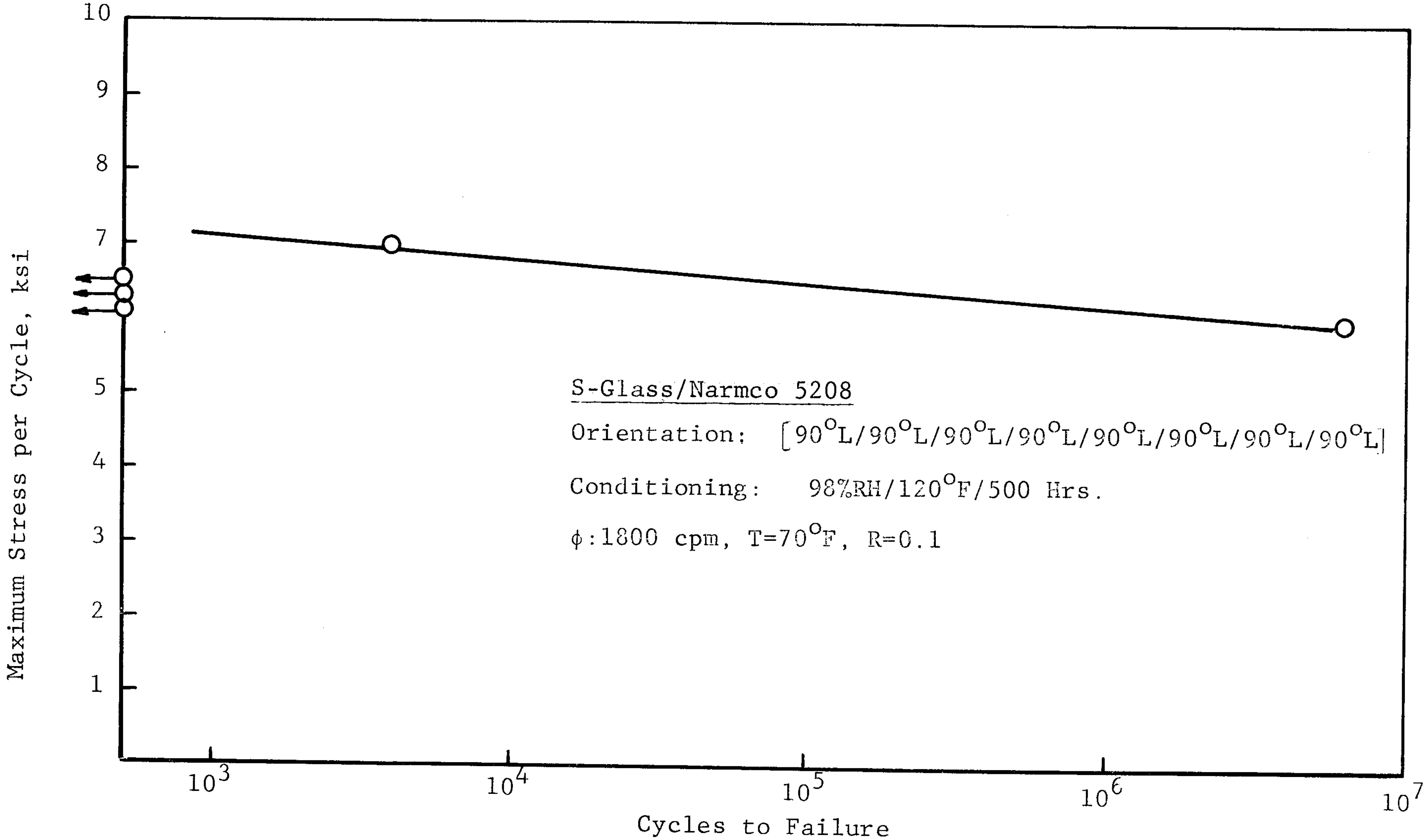


Figure 67 Fatigue S-N Curve For S-Glass/Narmco 5208 Composite, Tested at $R = 0.1$, $\phi = 30$ Hertz, and $T = 70^{o}F$ After Conditioning at 98% RH, and $120^{o}F$ for 500 Hours.

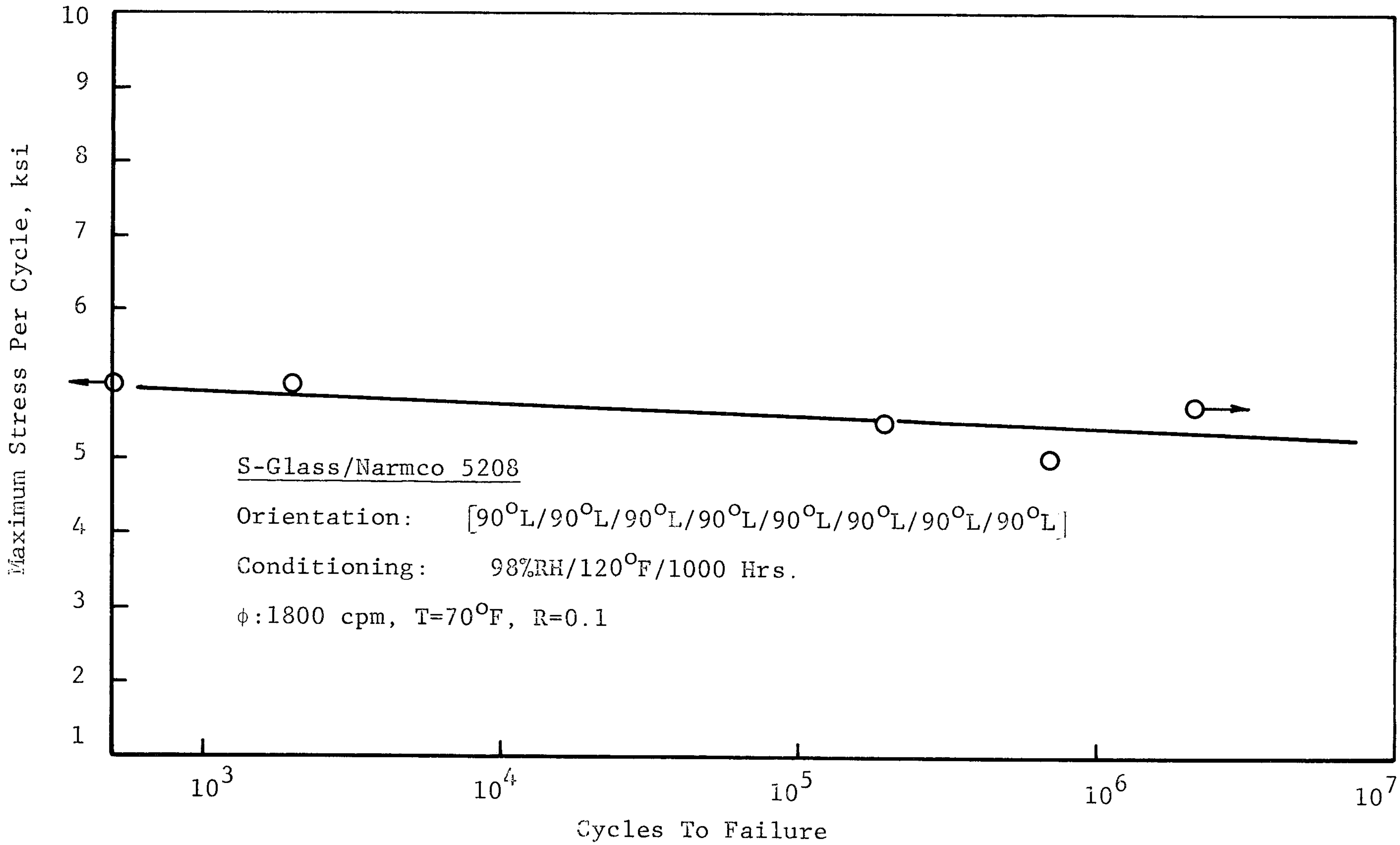


Fig. 68 Fatigue S-N Curve For S-Glass/Narmco 5208 Composite Tested At $R=0.1$, $\phi=30$ Hertz, and $T=70^{\circ}F$, After Conditioning At 98% RH and $120^{\circ}F$ For 1000 Hours

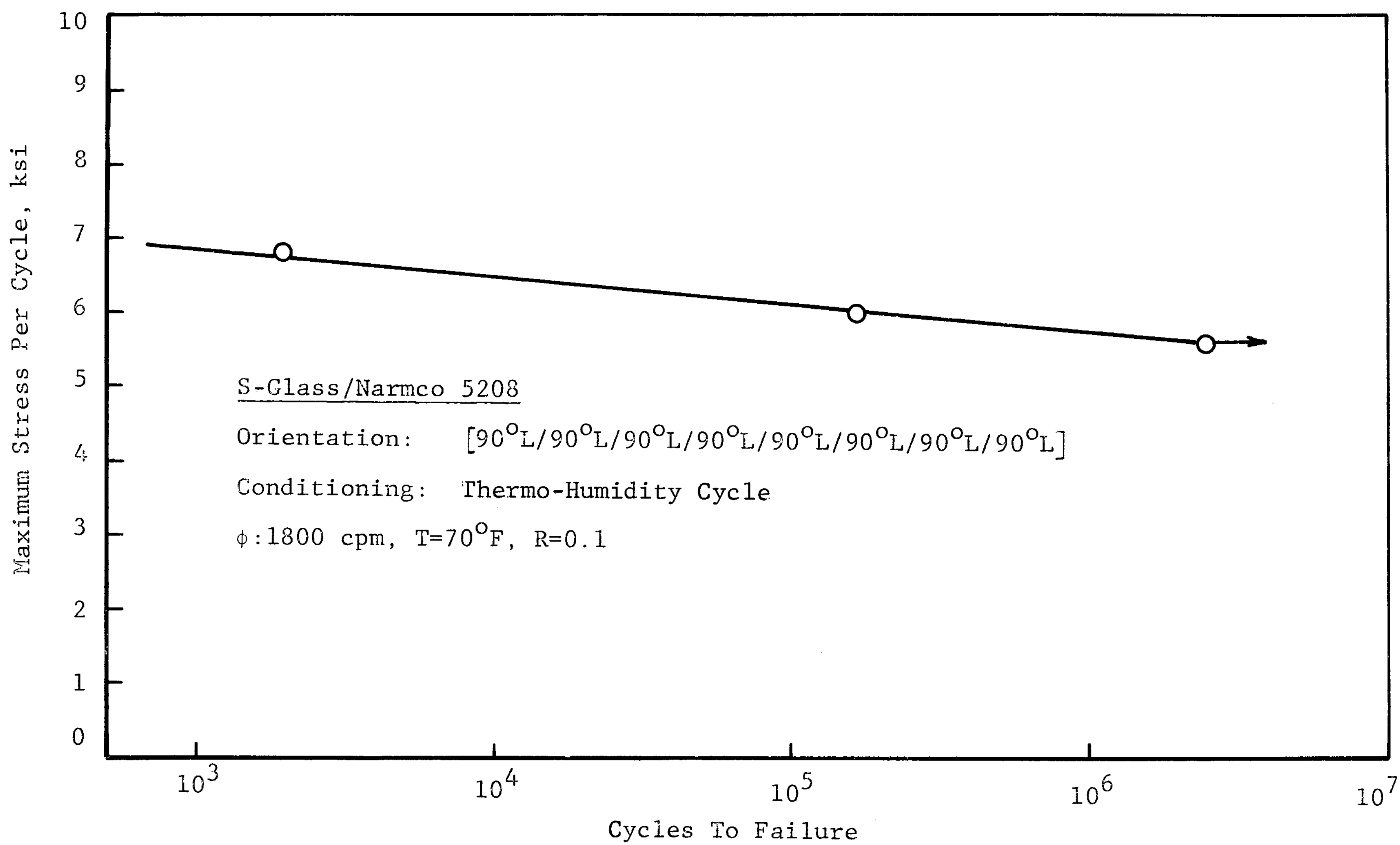


Fig. 69 Fatigue S-N Curve For S-Glass/Narmco 5208 Composite Tested at R=0.1 ϕ=30 Hertz and T=70°F, after Thermo-Humidity Cyclic Conditioning.

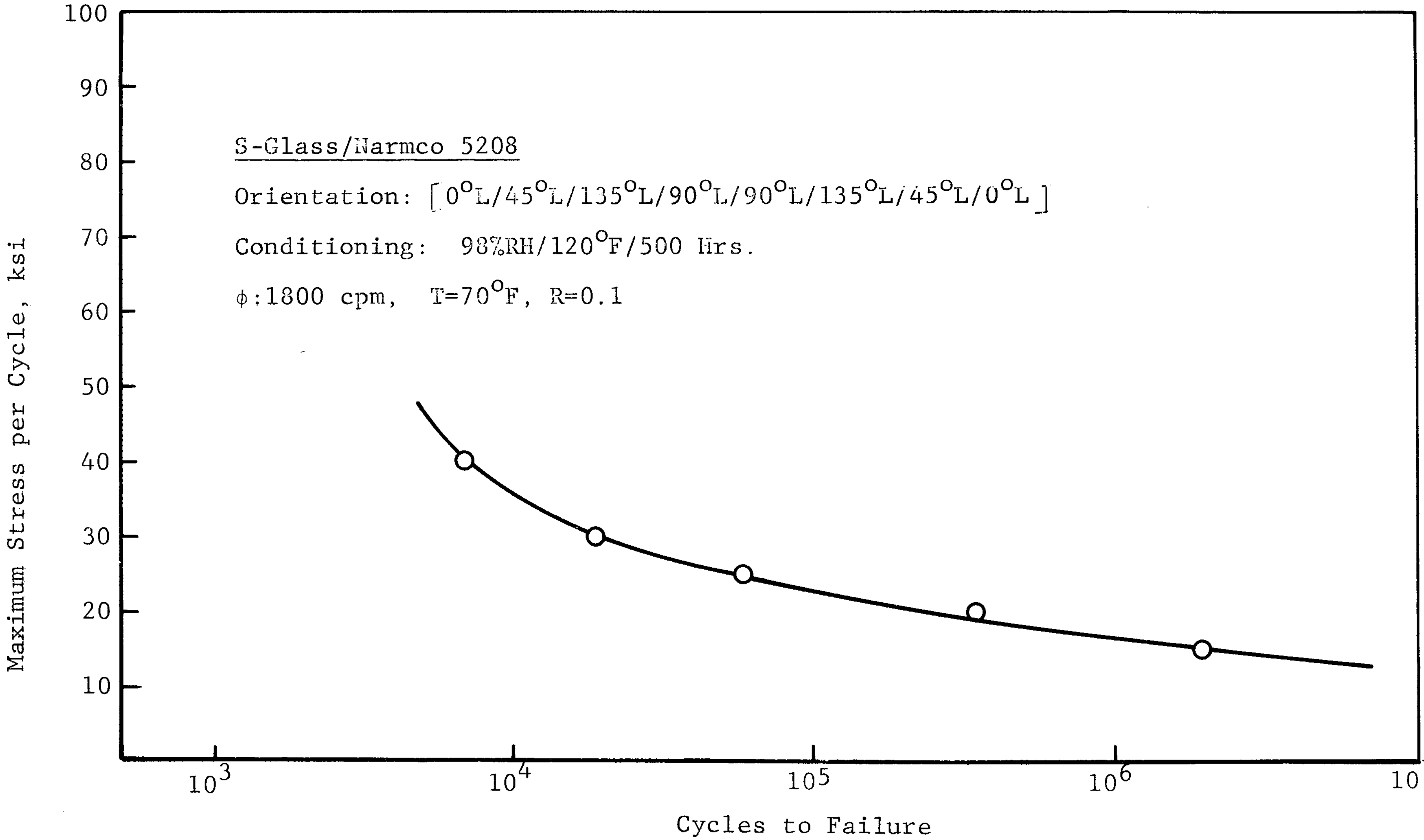


Figure 70 Fatigue S-N Curve For S-Glass/Narmco 5208 Composite, Tested at R = 0.1, ϕ = 30 Hertz, and T = 70°F After Conditioning at 98% RH, and 120°F for 500 Hours.

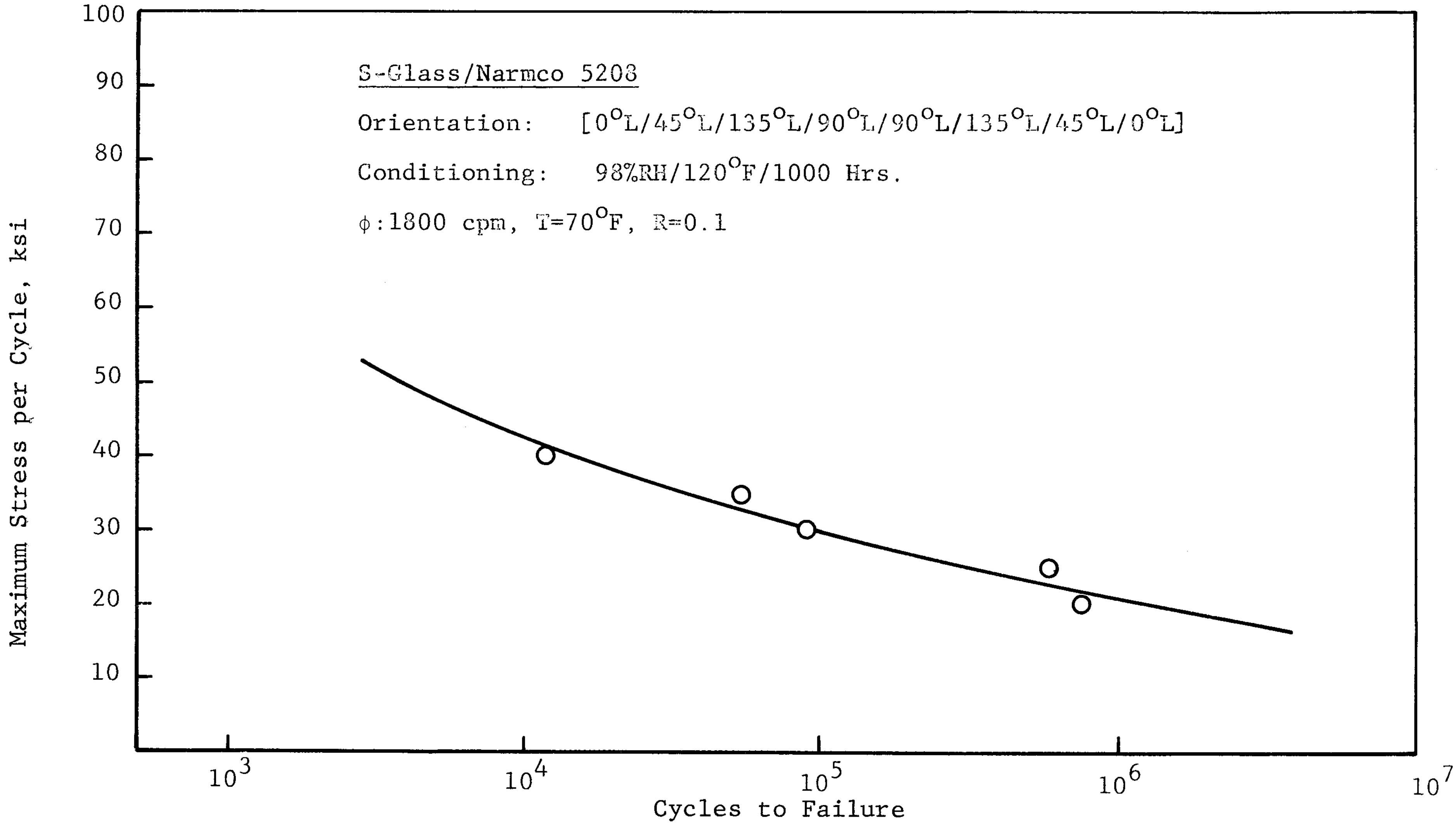


Figure 71 Fatigue S-N Curve For S-Glass/Narmco 5208 Composite, Tested at R = 0.1, ϕ = 30 Hertz, and T = 70°F After Conditioning at 98% RH, and 120°F for 1,000 Hours.

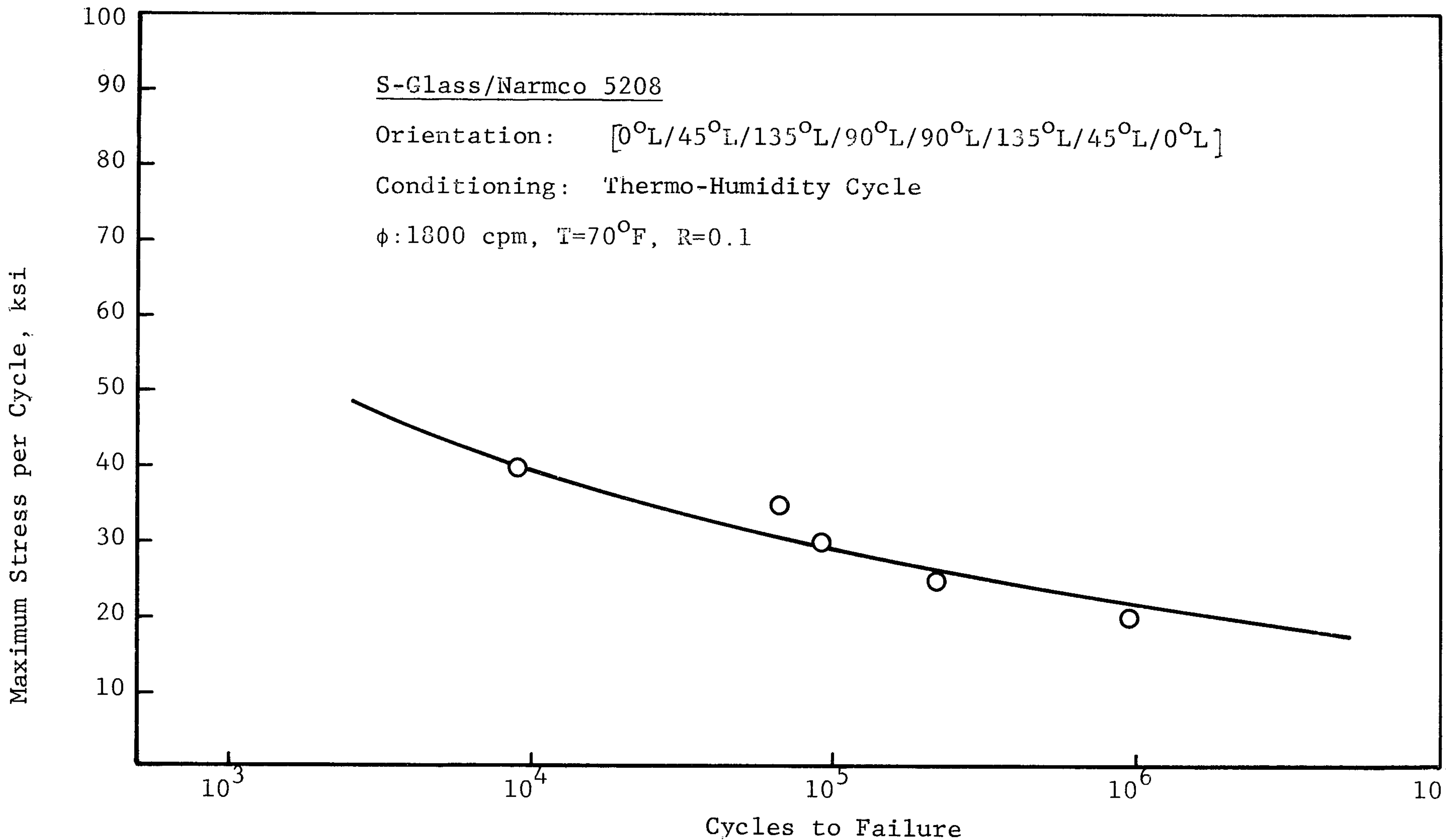


Figure 72 Fatigue S-N Curve For S-Glass/Narmco 5208 Composite, Tested at R = 0.1, ϕ = 30 Hertz, and T = 70°F After Thermo-Humidity Cyclic Conditioning.

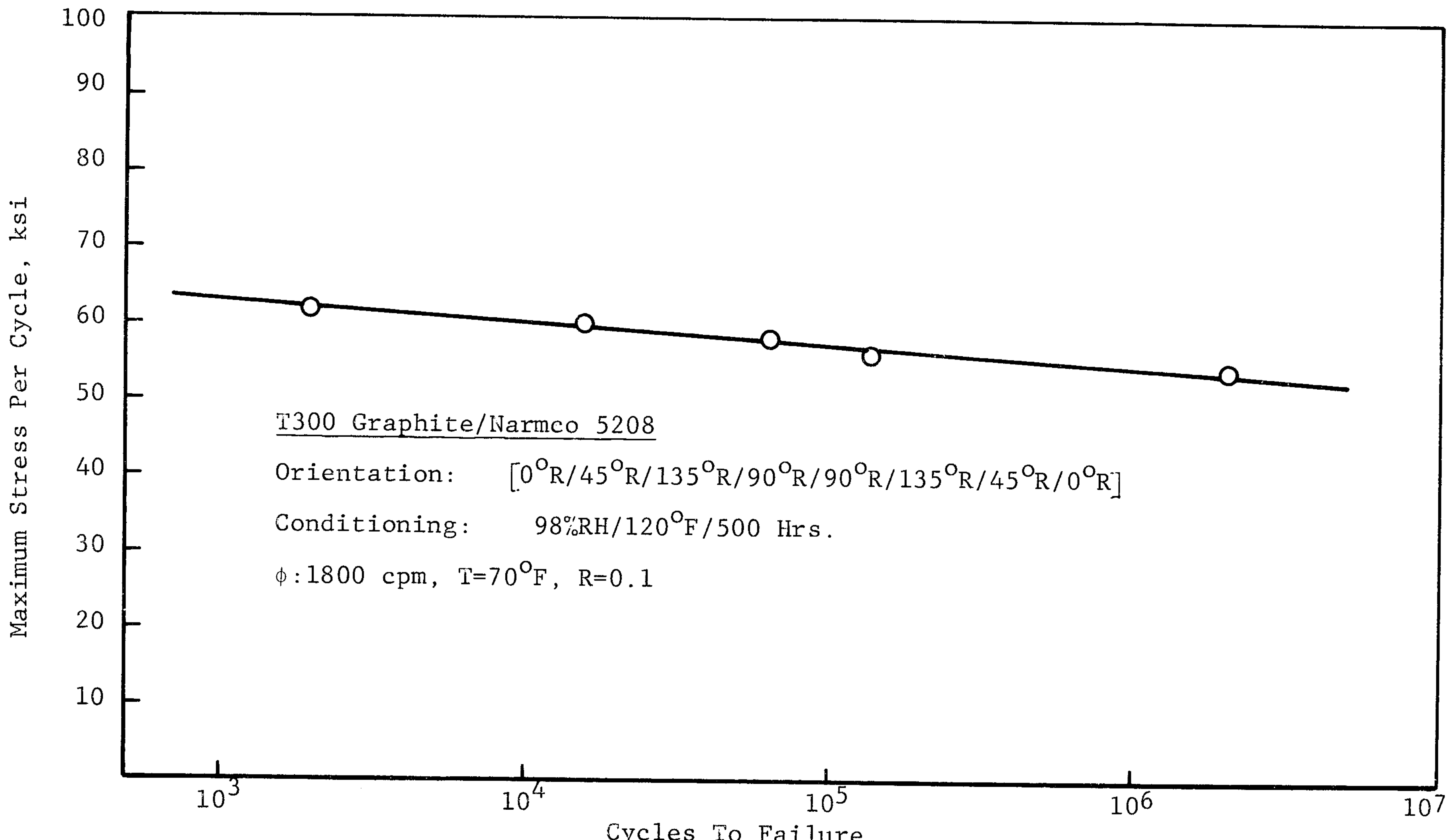


Fig. 73 Fatigue S-N Curve For T300 Graphite/Narmco 5208 Composite Tested At R=0.1, ϕ=30 Hertz, and T=70°F, After Conditioning at 98% RH, and 120°F For 500 Hours

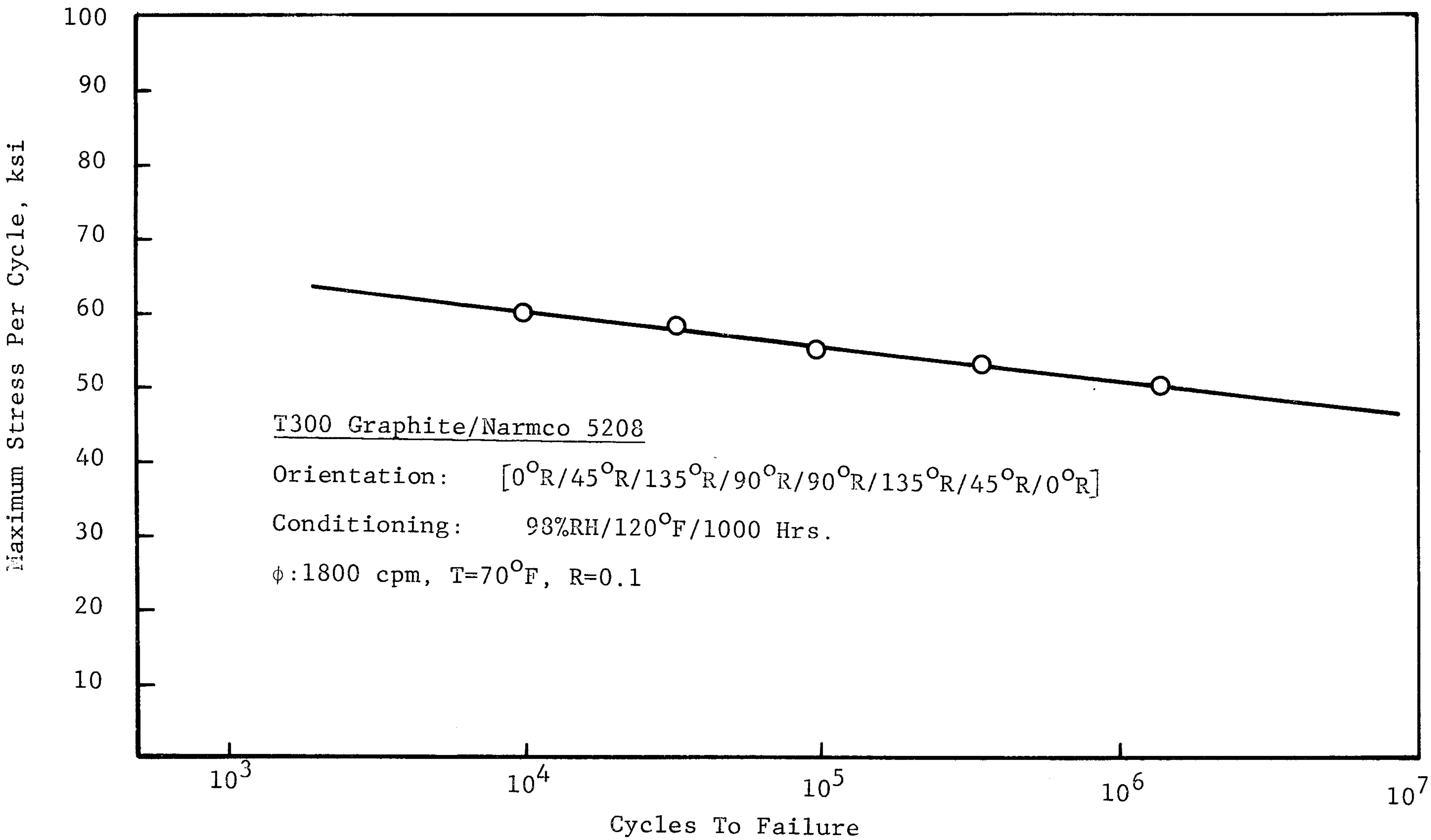


Fig. 74 Fatigue S-N Curve For T300 Graphite/Narmco 5208 Composite Tested at R=0.1, ϕ=30 Hertz, and T=70^{o}F, After Conditioning at 98% RH, and 120^{o}F For 1000 Hours

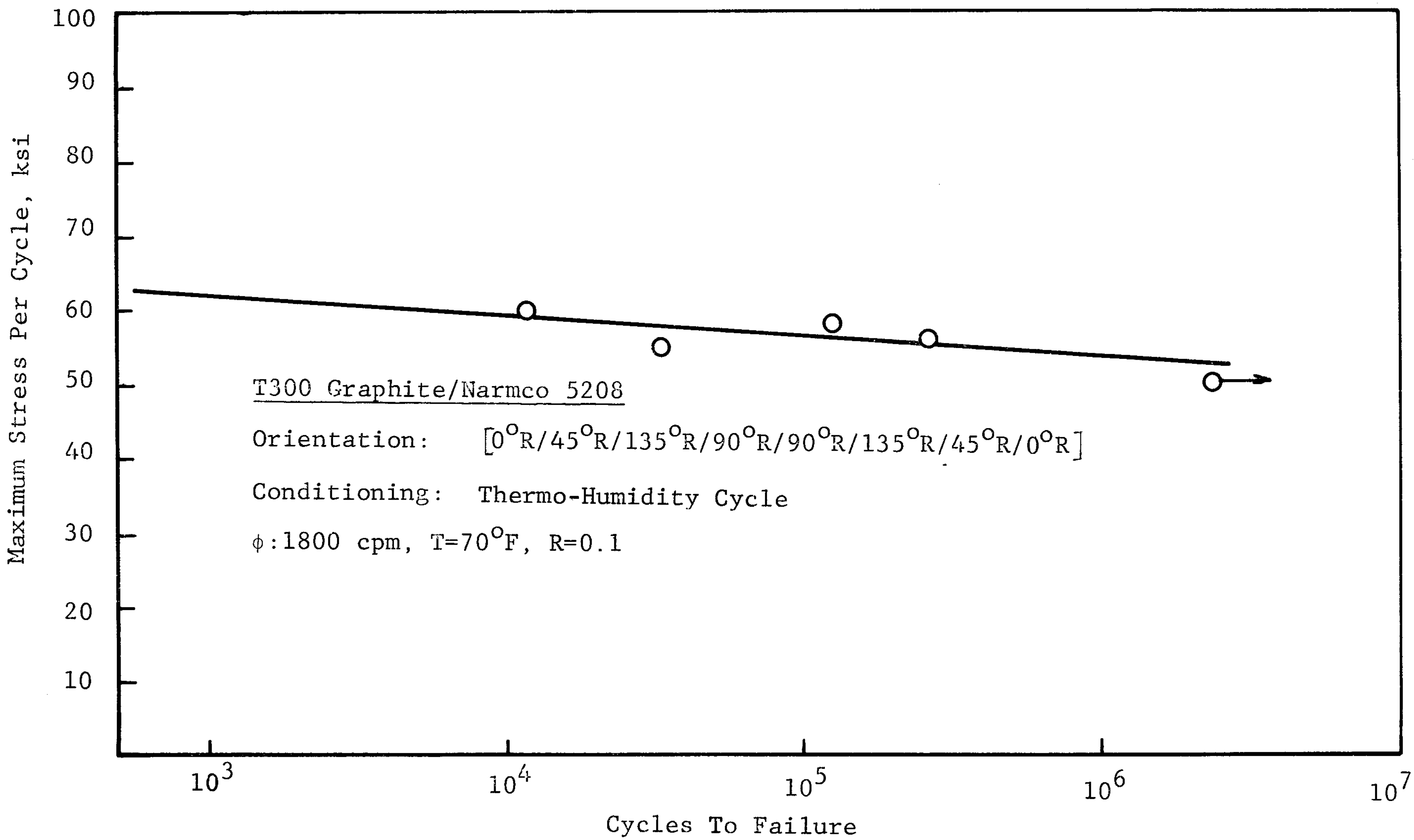


Fig.75 Fatigue S-N Curve For T300 Graphite/Narmco Composite Tested at $R=0.1$, $\phi=30$ Hertz, and $T=70^{\circ}F$, After Thermo-Humidity Cyclic Conditioning.

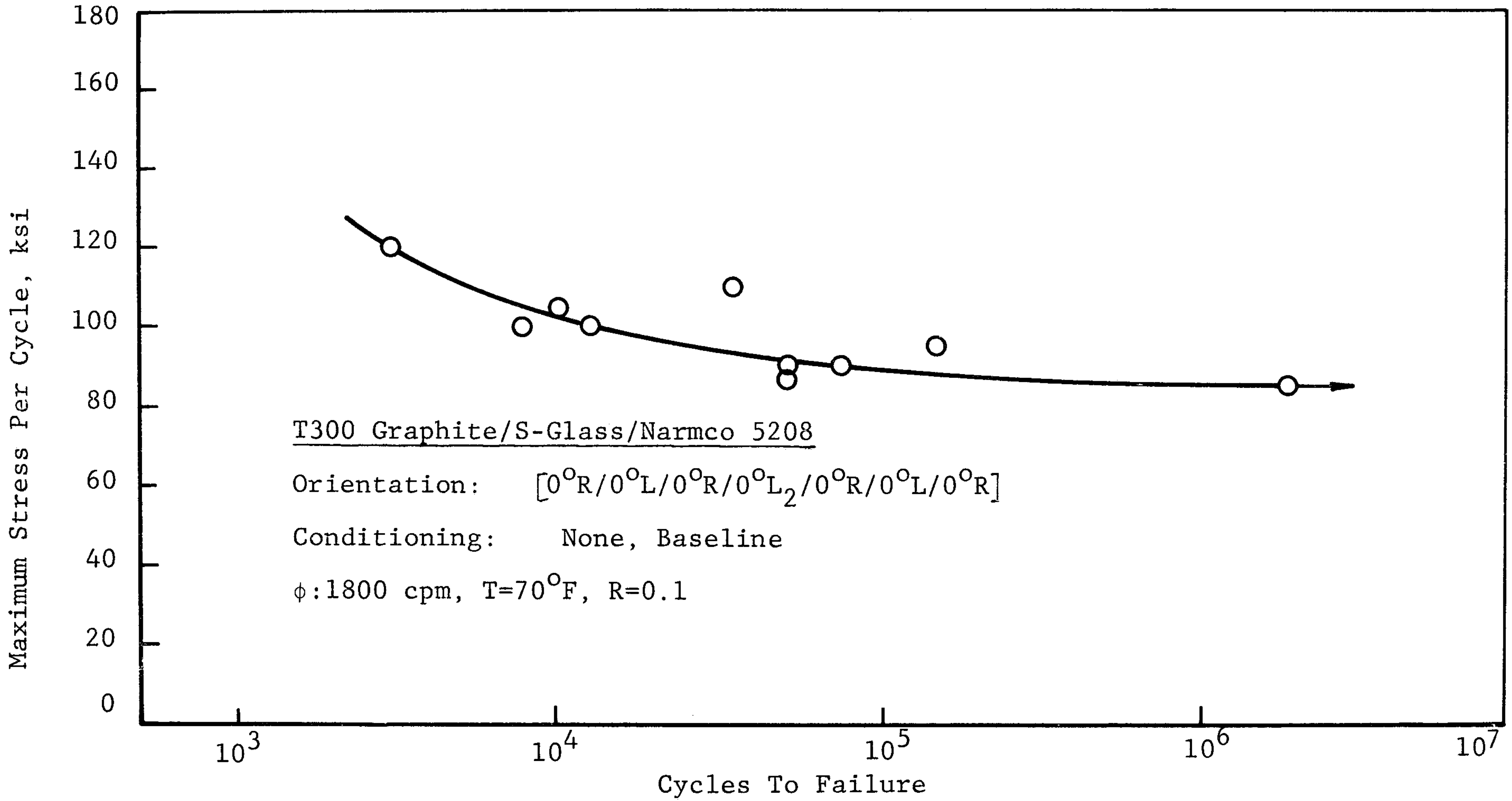


Fig. 76 Fatigue S-N Curve For S-Glass/T-300 Graphite/Narmco 5208 Hybrid Composite, Tested at $R=0.1$, $\phi=30$ Hertz, and $T=70^{o}F$

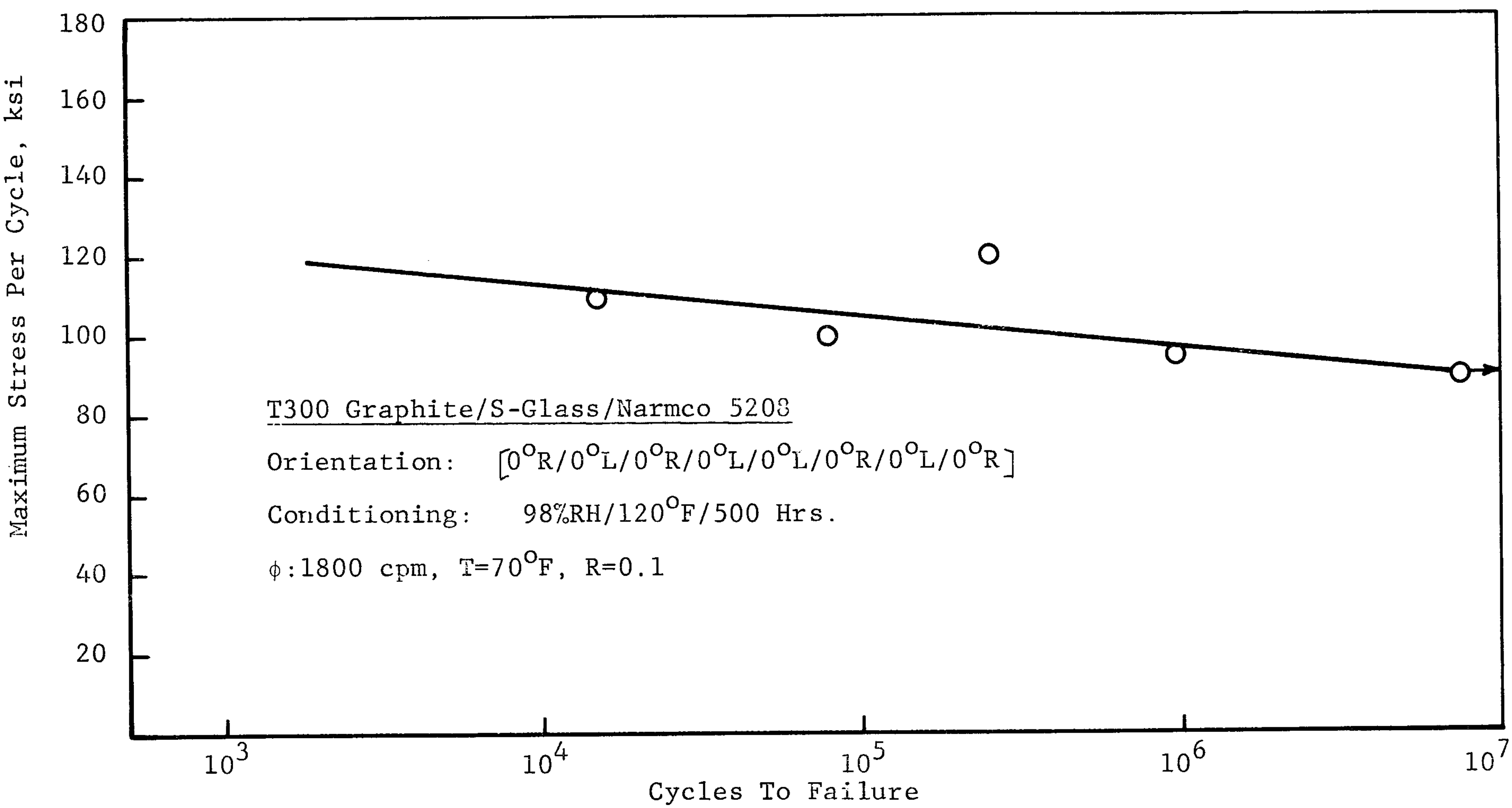


Fig. 77 Fatigue S-N Curve For T300 Graphite/S-Glass/Narmco 5208 Hybrid Composite Tested at $R=0.1$, $\phi=30$ Hertz, and $T=70^{o}F$, After Conditioning at 98% and $120^{o}F$ For 500 Hours

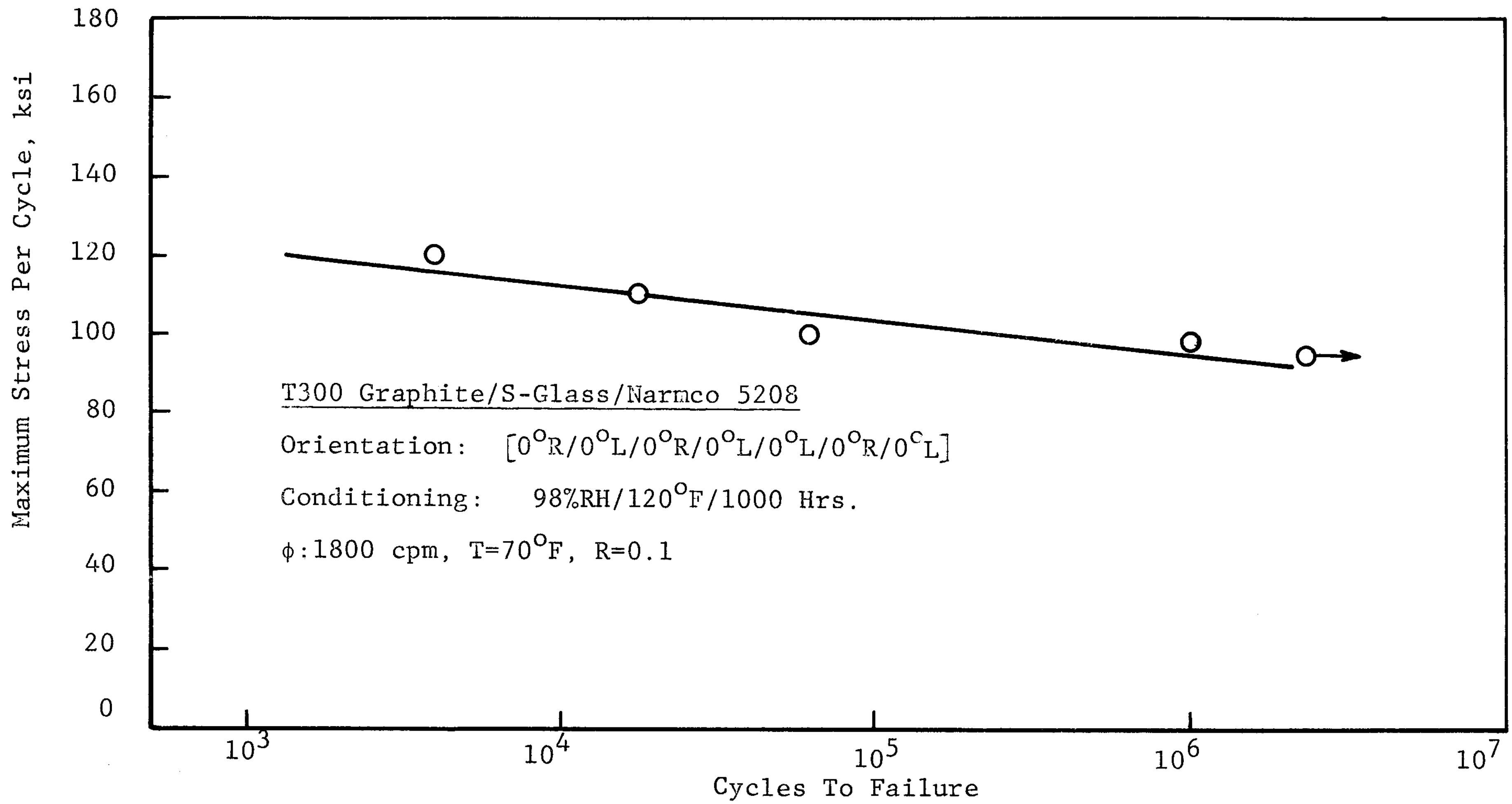


FIG. 78 FATIGUE S-N CURVE FOR T300 GRAPHITE/S-GLASS/NARMCO 5208 HYBRID COMPOSITE, TESTED AT R=0.1, ϕ=30 HERTZ, AND T=70°F AFTER CONDITIONING AT 98% R.H., AND 120°F FOR 1000 HOURS

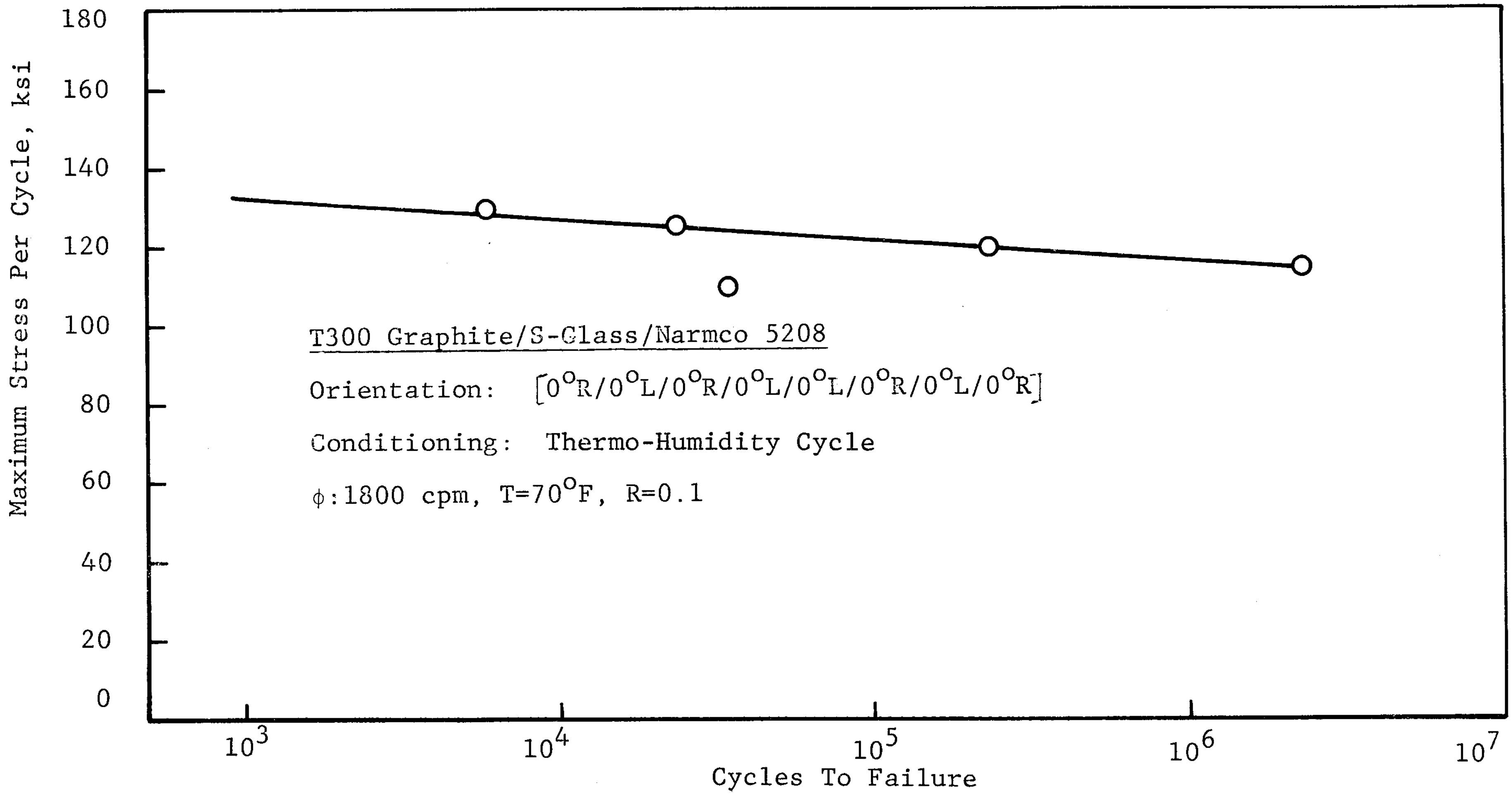


Fig. 79 Fatigue S-N Curve for T300 Graphite/S-Glass/Narmco 5208 Hybrid Composite Tested at R=0.1, ϕ=30 Hertz, and T=70°F after Thermo-Humidity Cyclic Conditioning.

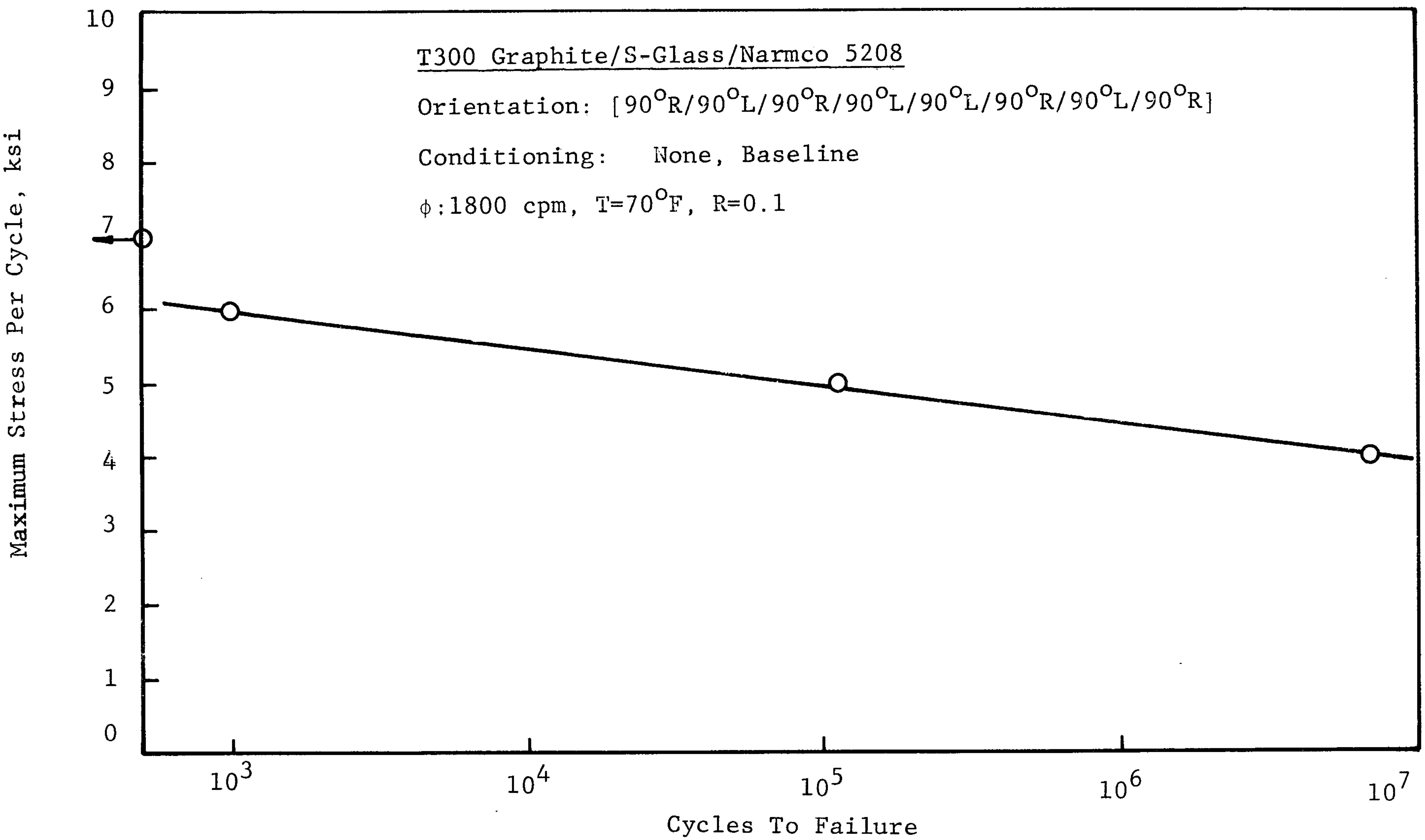


FIG.80 FATIGUE S-N CURVE FOR T300 GRAPHITE/S-GLASS/NARMCO 5208 HYBRID COMPOSITE, TESTED AT R=0.1, ϕ=30 HERTZ, AND T=70°F

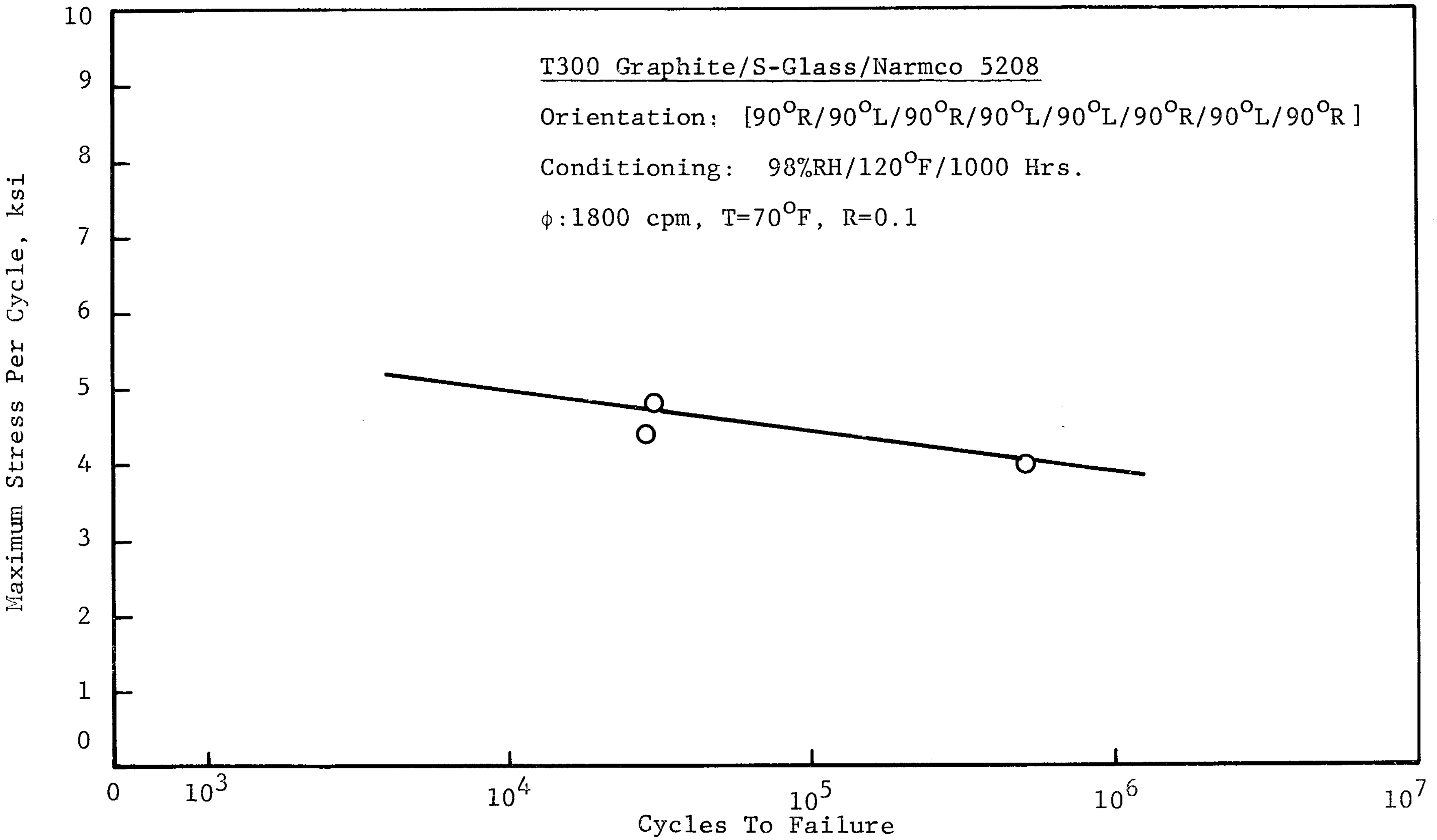


Fig. 81 Fatigue S-N Curve For T300 Graphite/S-Glass/Narmco 5208 Hybrid Composite, Tested at $R=0.1$, $\phi=30$ Hertz, and $T=70^{\circ}F$, After Conditioning at 90% RH and $120^{\circ}F$ for 1,000 Hours

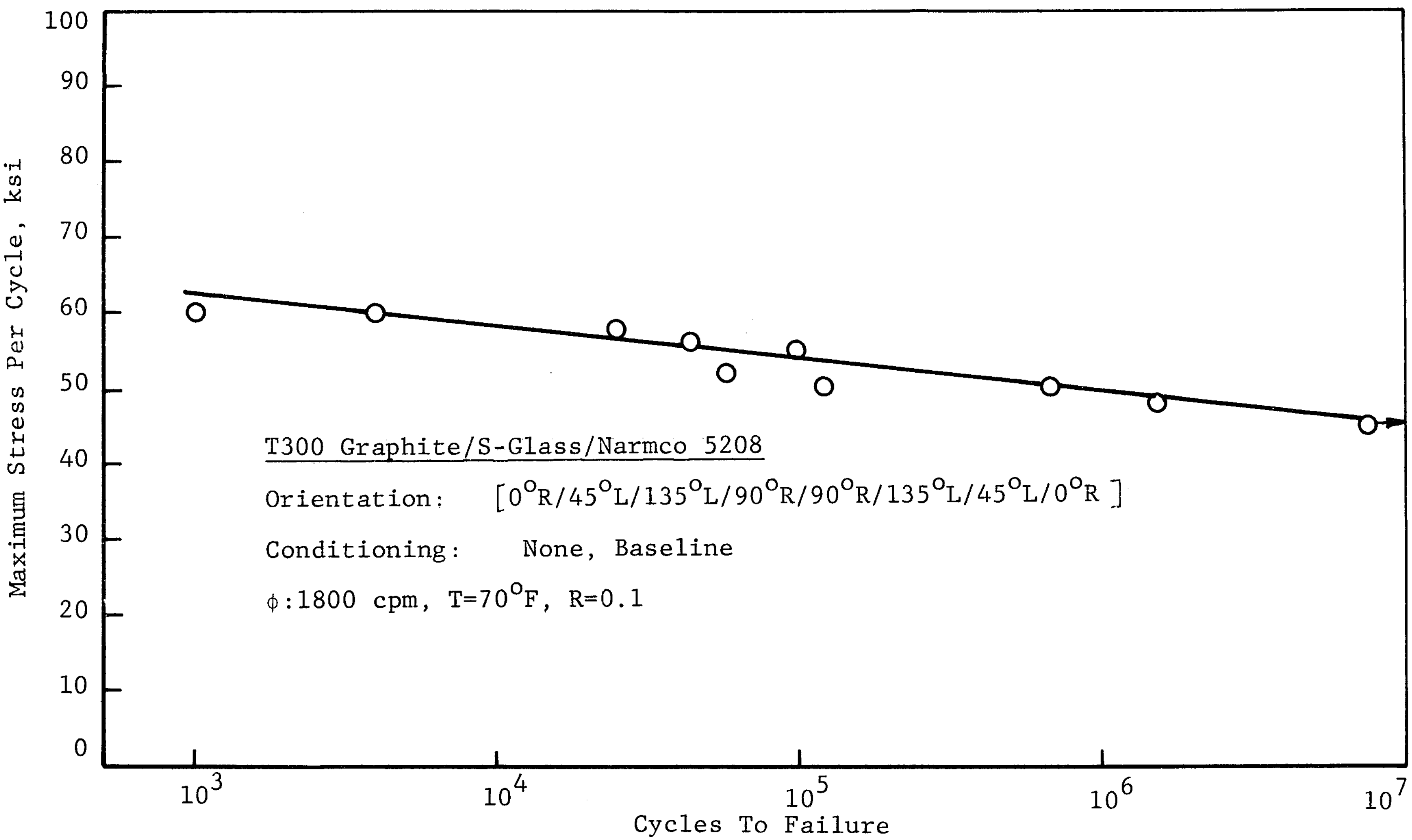


Fig. 82 Fatigue S-N Curve For S-Glass/T-300 Graphite/Narmco 5208 Hybrid Composite, Tested at R=0.1, ϕ=30 Hertz, and T=70^{o}F.

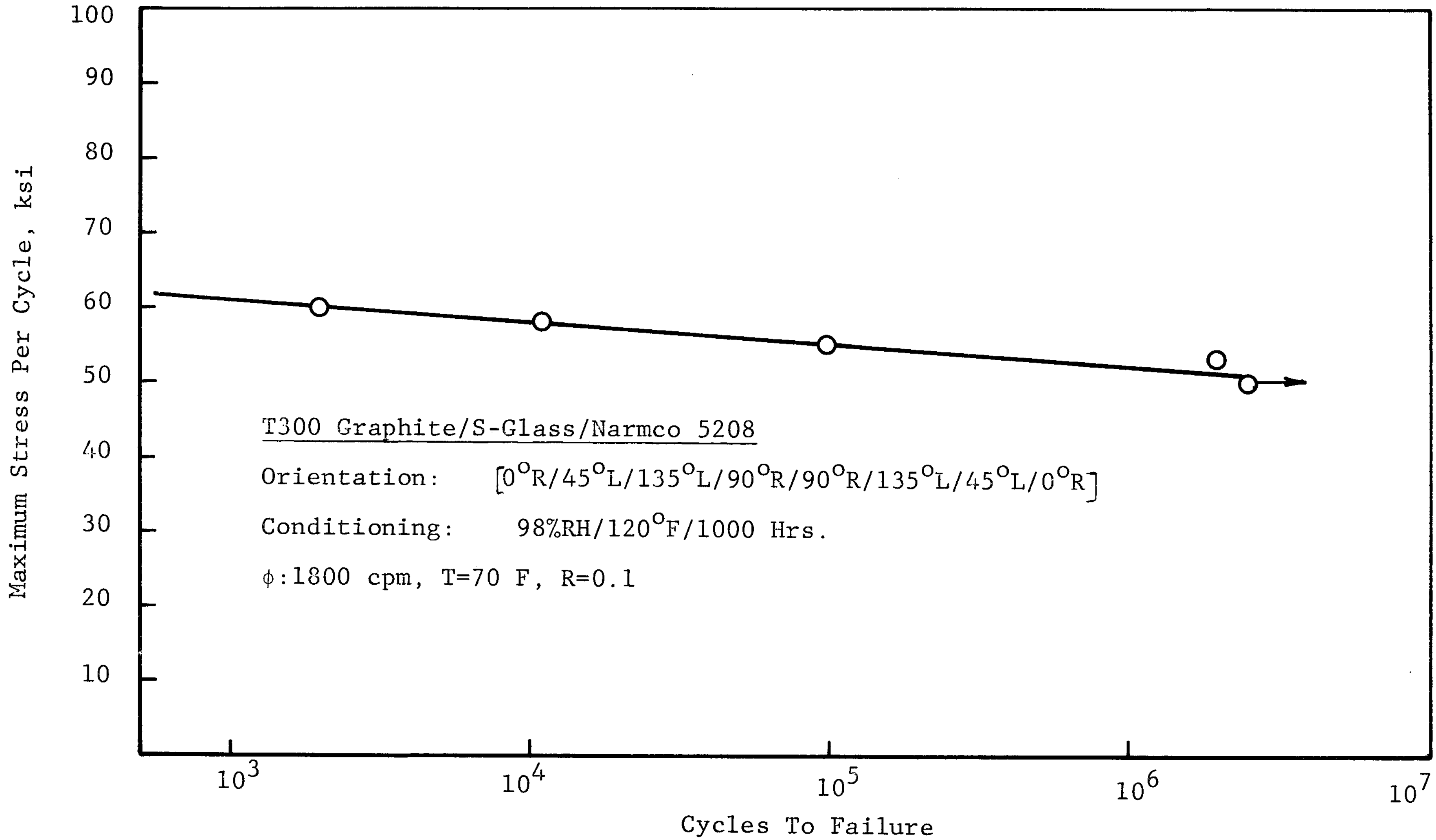


Fig. 83 Fatigue S-N Curve For T300 Graphite/S-Glass/Narmco 5208 Hybrid Composite Tested at R=0.1, ϕ=30 Hertz, and T=70°F, After Conditioning at 98% RH, and 120°F For 1000 Hours

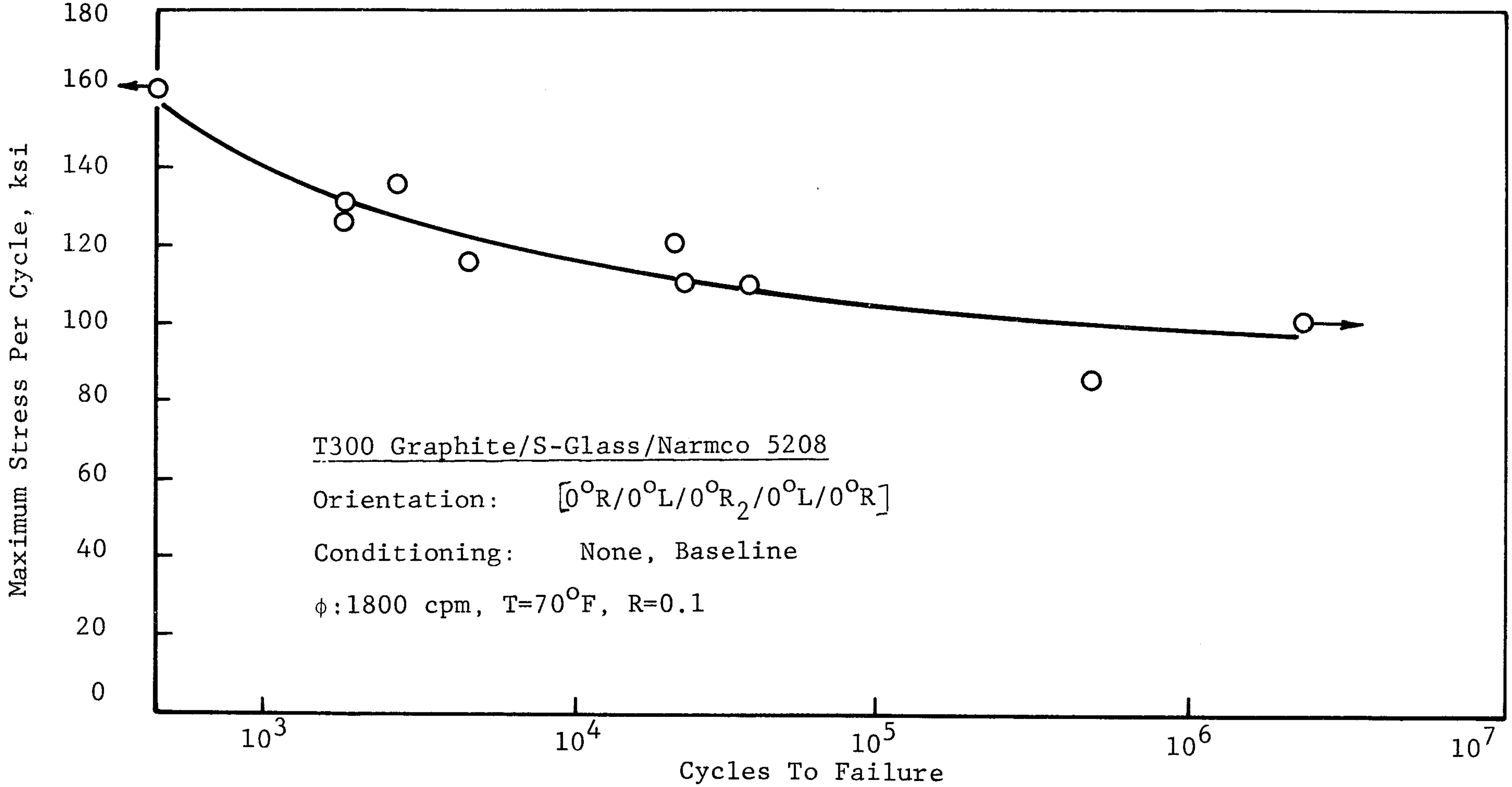


Fig. 84 Fatigue S-N Curve For S-Glass/T-300 Graphite/Narmco 5208 Hybrid Composite, Tested at R=0.1, ϕ=30 Hertz, and T=70^{o}F

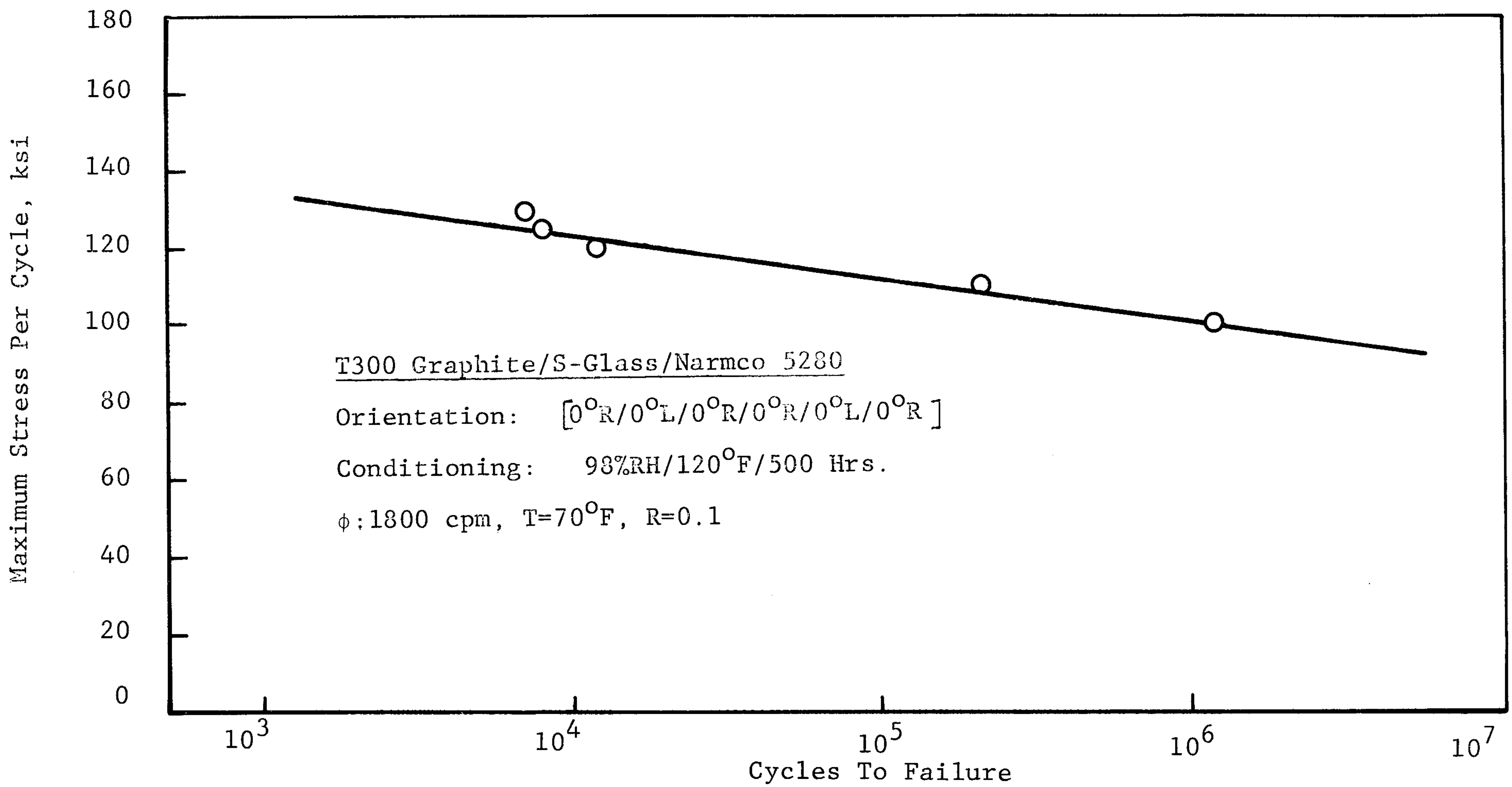


FIG. 85 FATIGUE S-N CURVE FOR T300 GRAPHITE/S-GLASS/NARMCO 5208 HYBRID COMPOSITE, TESTED AT R=0.1, ϕ=30 HERTZ, AND T=70°F AFTER CONDITIONING AT 98% R.H., AND 120°F FOR 500 HOURS

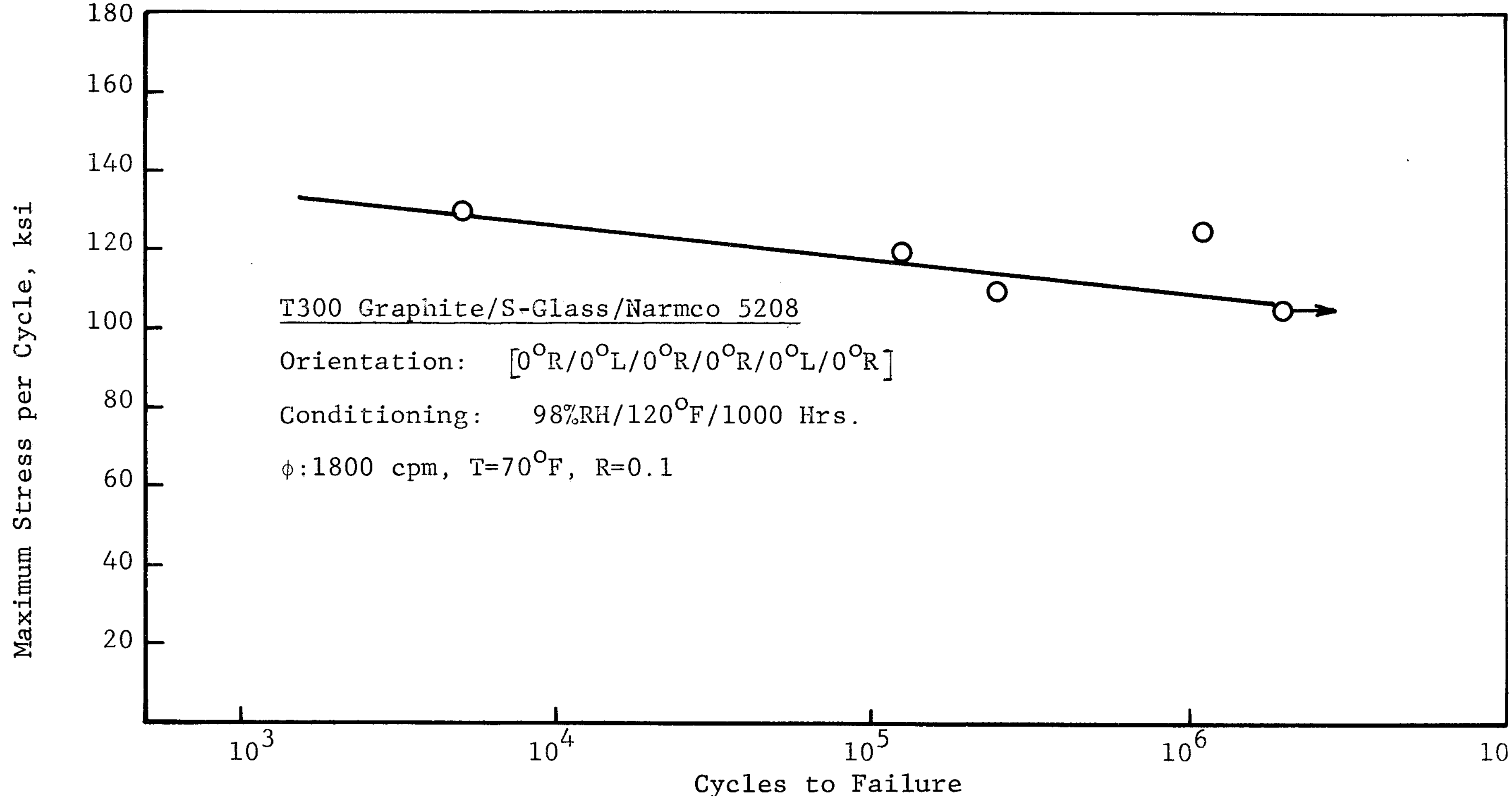


Figure 86 Fatigue S-N Curve For T300 Graphite/S-Glass/Narmco 5208 Hybrid Composite, Tested at R = 0.1, ϕ = 30 Hertz, and T = 70°F After Conditioning at 98% RH, and 120°F For 1,000 Hours.

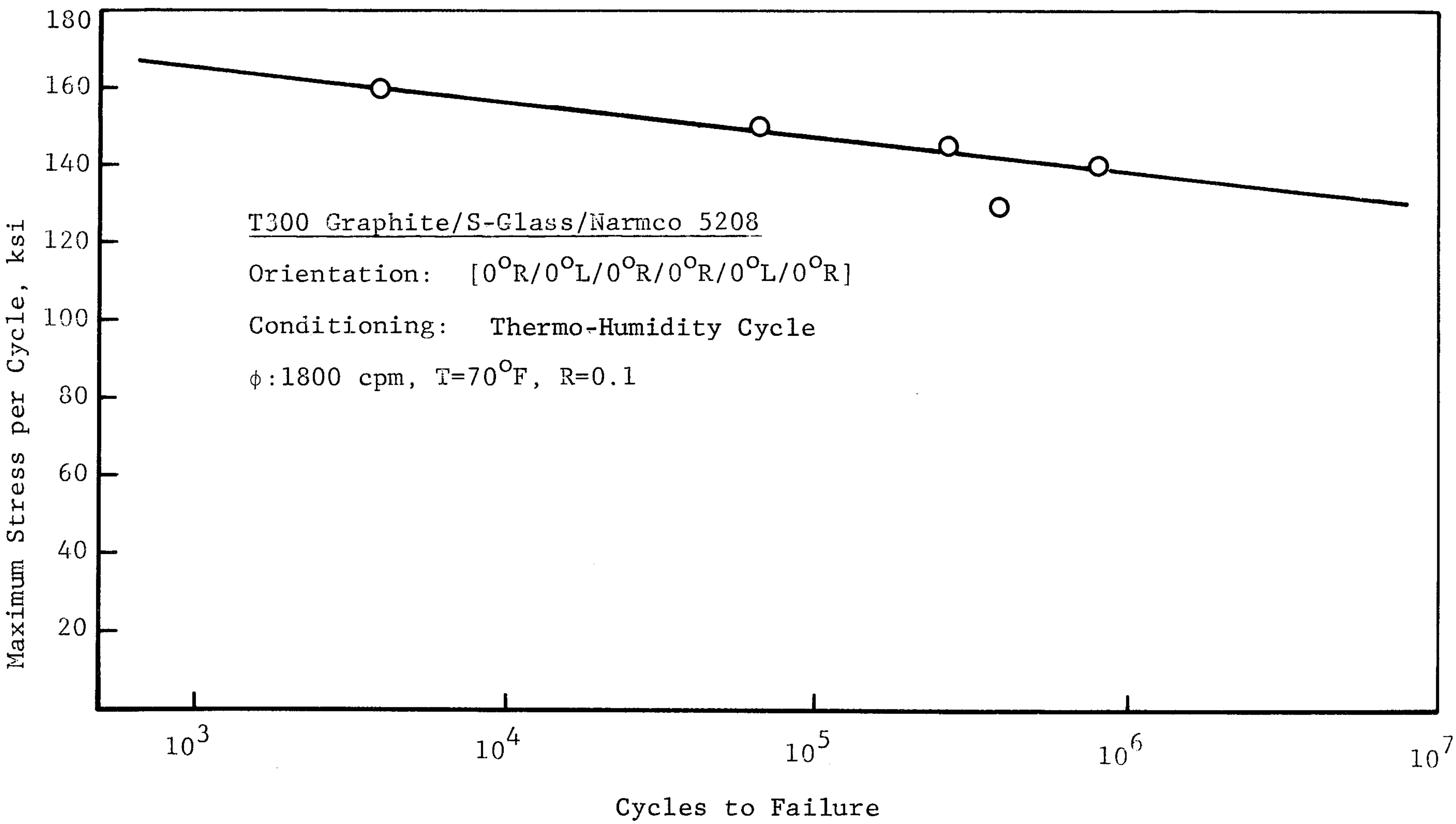


Figure 87 Fatigue S-N Curve for T300 Graphite/S-Glass/Narmco 5208 Hybrid Composite. Tested at $R=0.1$, $\phi=30$ Hertz, and $T=70^{\circ}F$ after Thermo-Humidity Cyclic Conditioning.

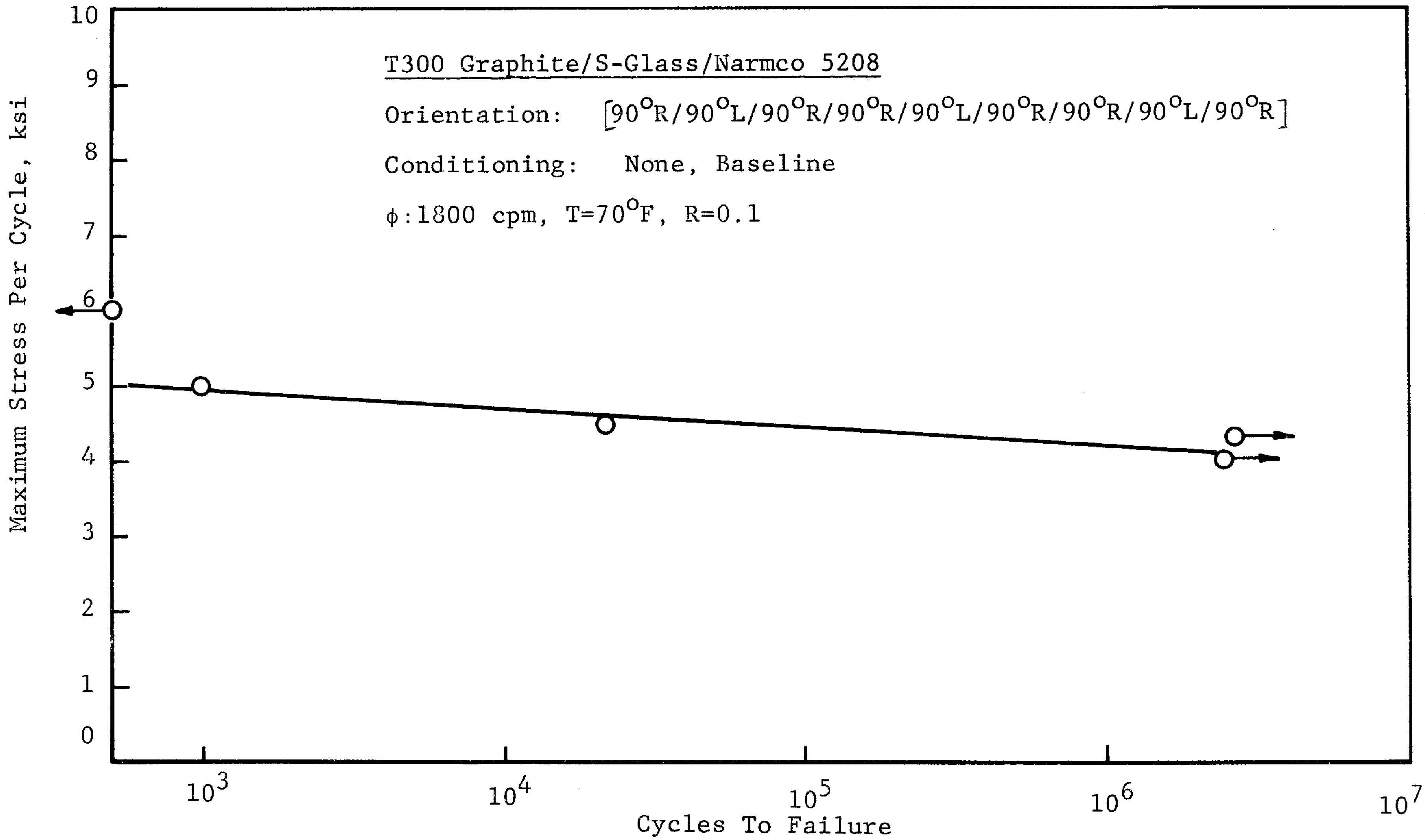


Fig. 88 Fatigue S-N Curve for S-Glass/T-300 Graphite/Narmco 5208 Hybrid Composite, Tested at $R=0.1$ $\phi=30$ Hertz, and $T=70^{o}F$

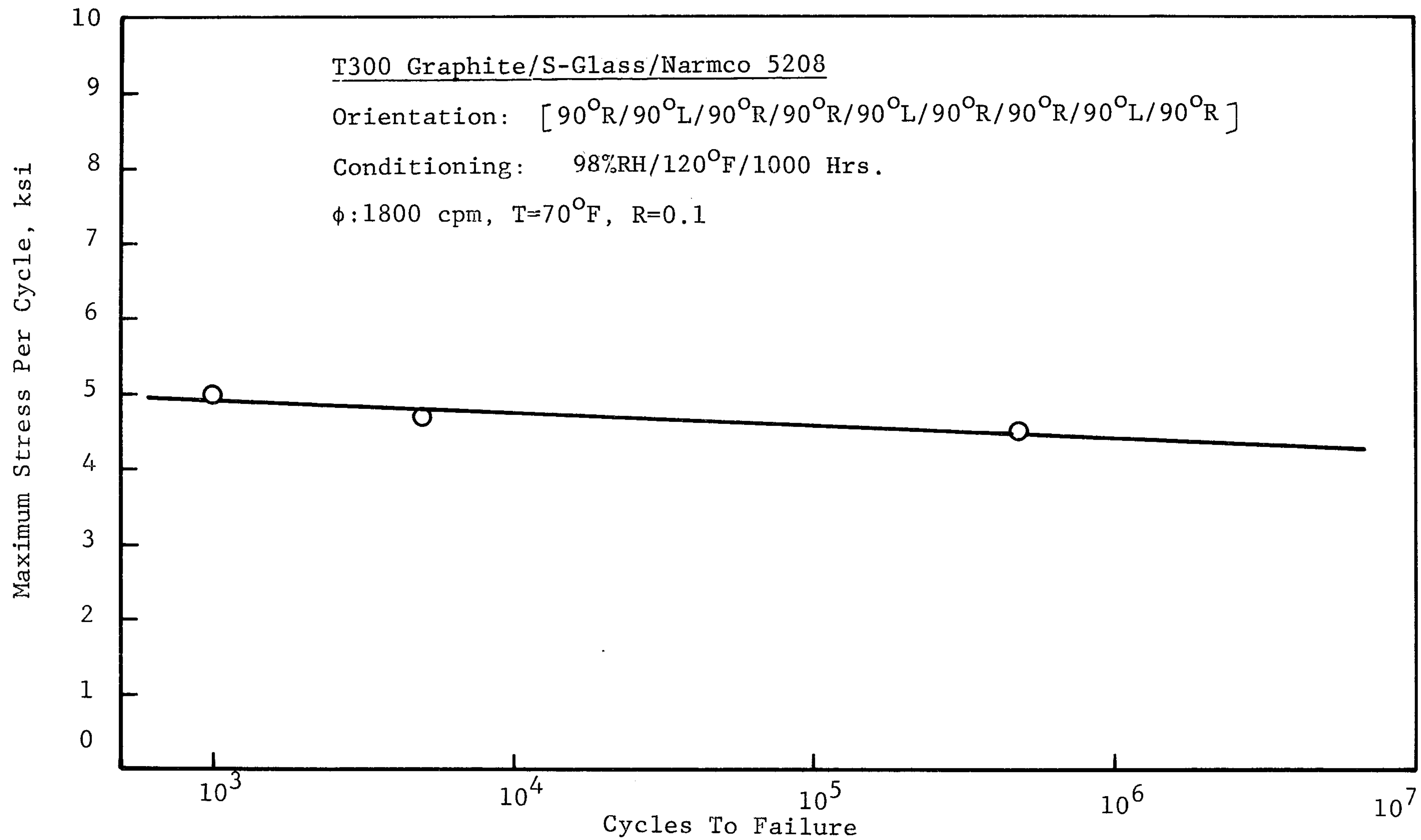


Fig. 89 Fatigue S-N Curve For T300 Graphite/S-Glass/Narmco 5208 Hybrid Composite Tested at $R=0.1$, $\phi=30$ Hertz, and $T=70^{\circ}F$ After Conditioning at 98% RH, and $120^{\circ}F$ for 1000 Hours

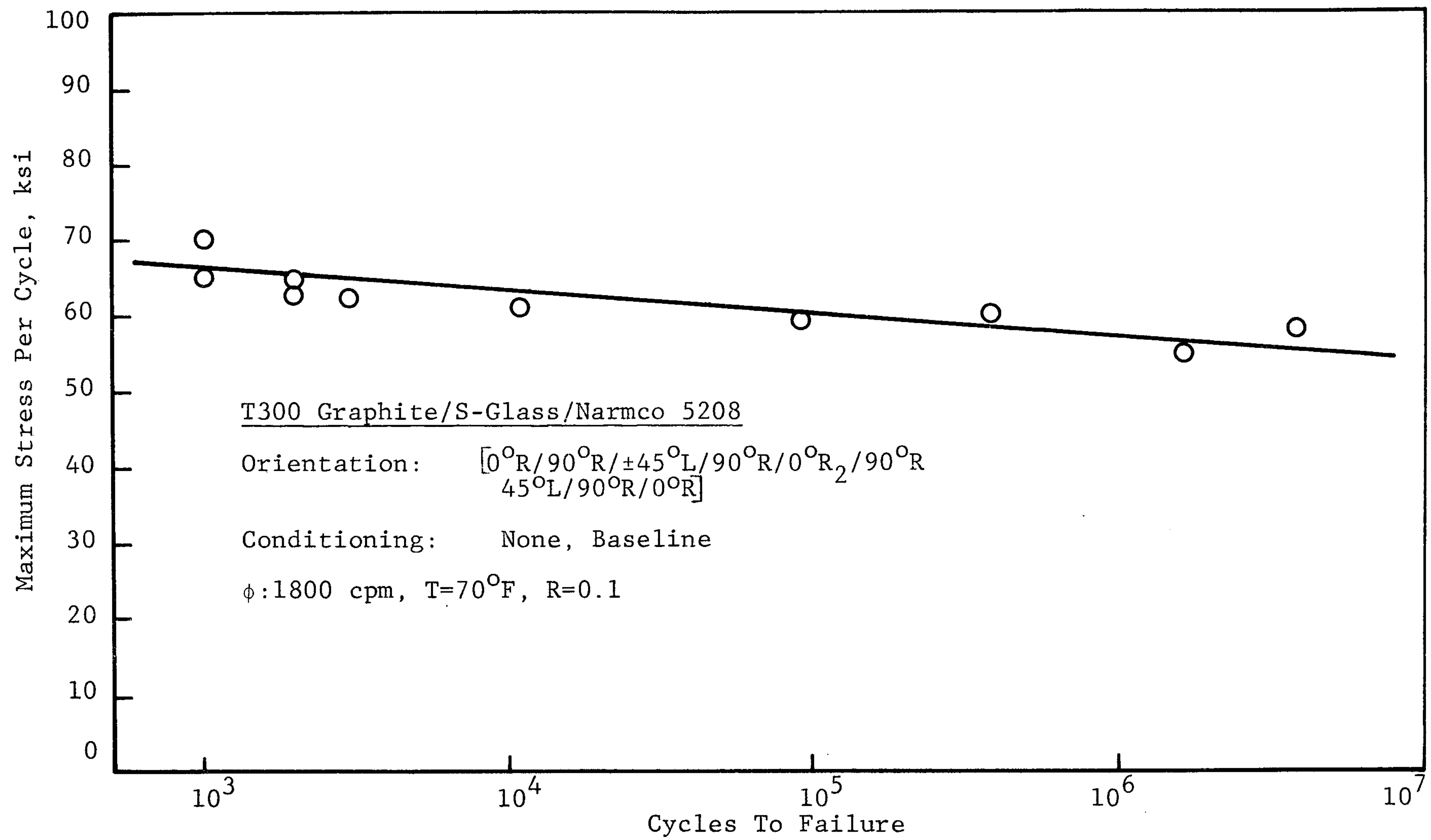


Fig. 90 Fatigue S-N Curve For S-Glass/T-300 Graphite/Narmco 5208 Hybrid Composite, Tested at R=0.1, ϕ=30 Hertz, and T=70^oF

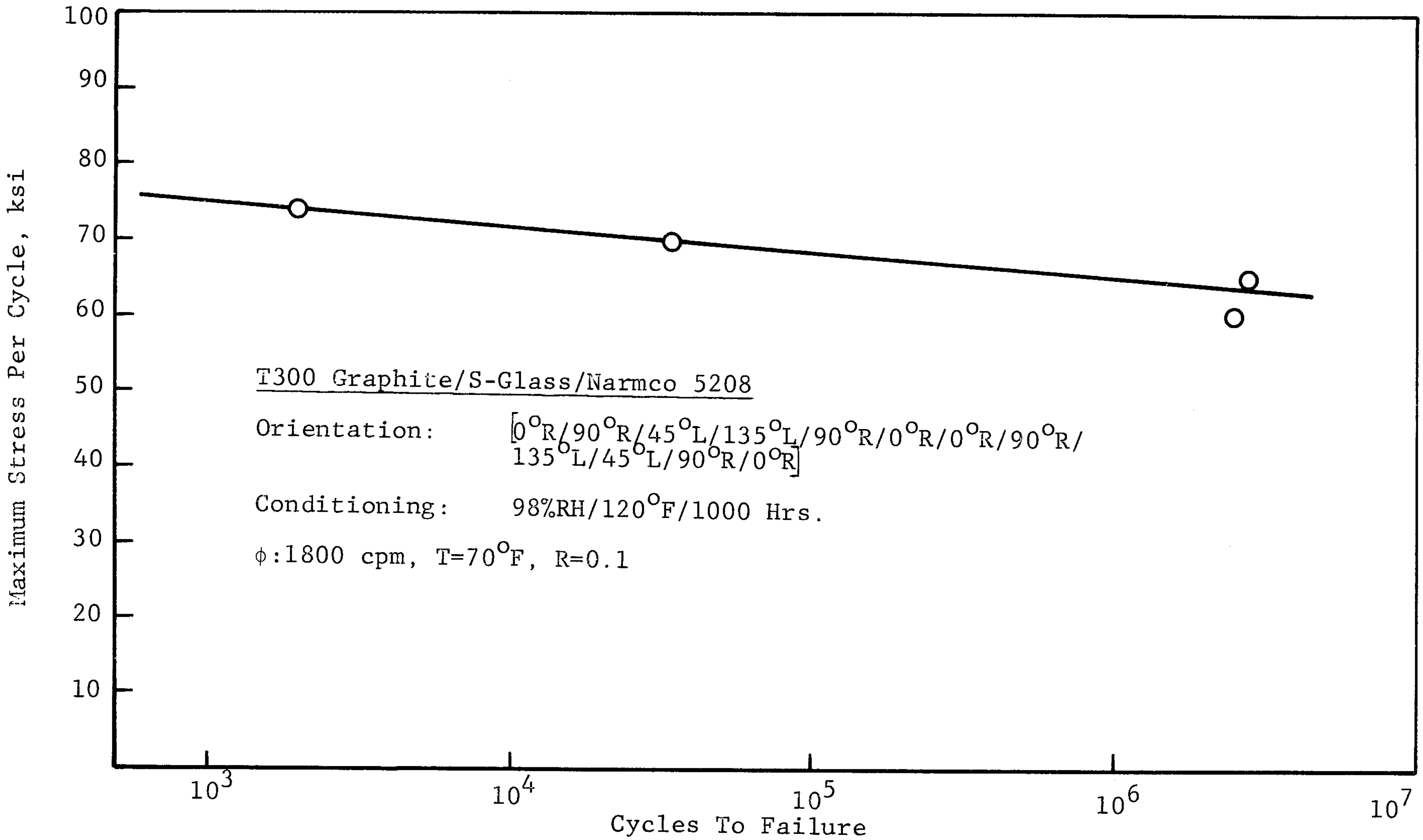


Fig. 91 Fatigue S-N Curve For T300 Graphite/S-Glass/Narmco 5208 Hybrid Composite Tested at R=0.1, ϕ=30 Hertz, and T=70°F, After Conditioning At 98% RH, and 120°F For 1000 Hours

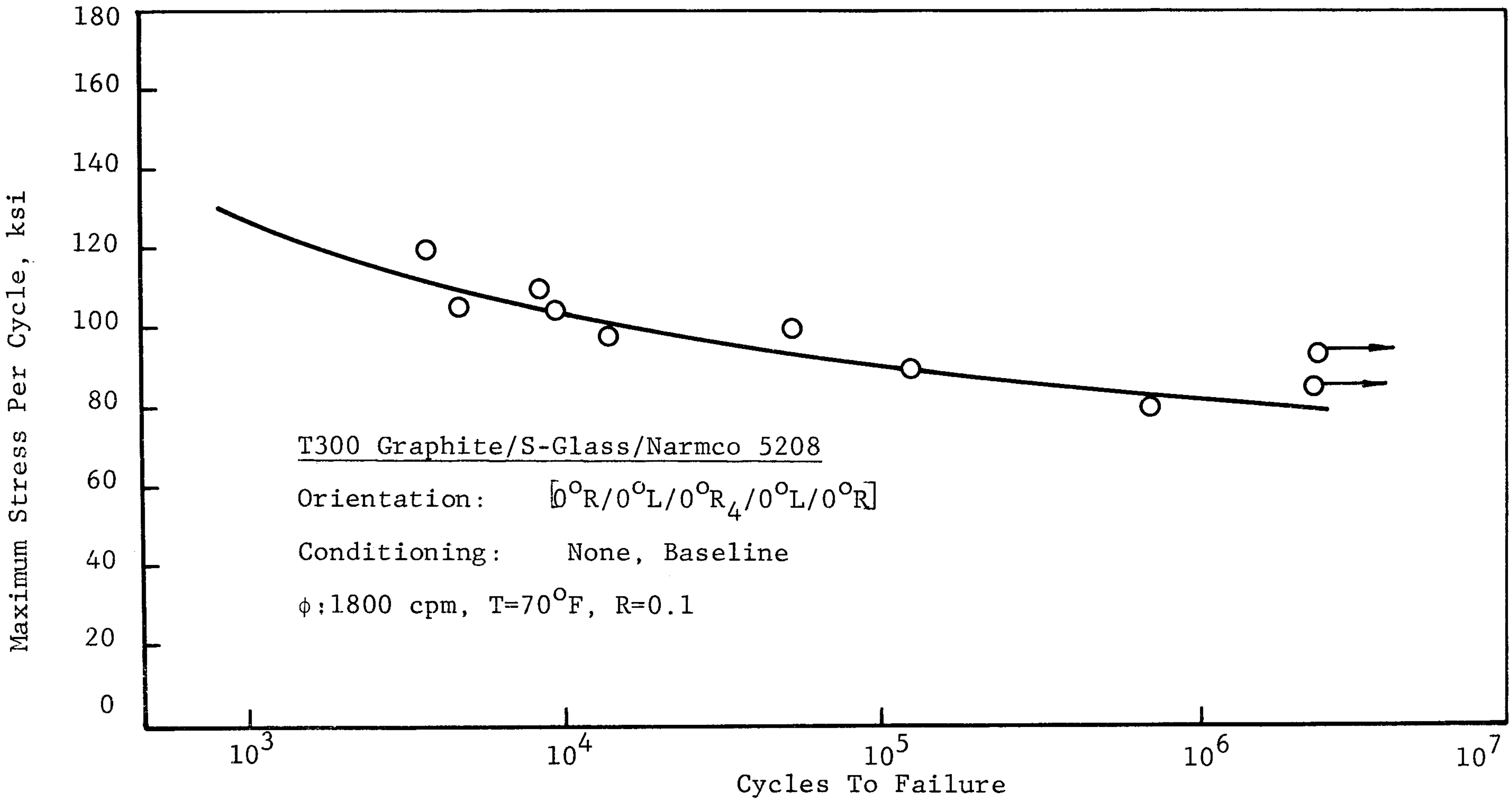


Fig. 92 Fatigue S-N Curve for S-Glass/T-300 Graphite/Narmco 5208 Hybrid Composite, Tested at R=0.1, ϕ=30 Hertz, and T=70°F

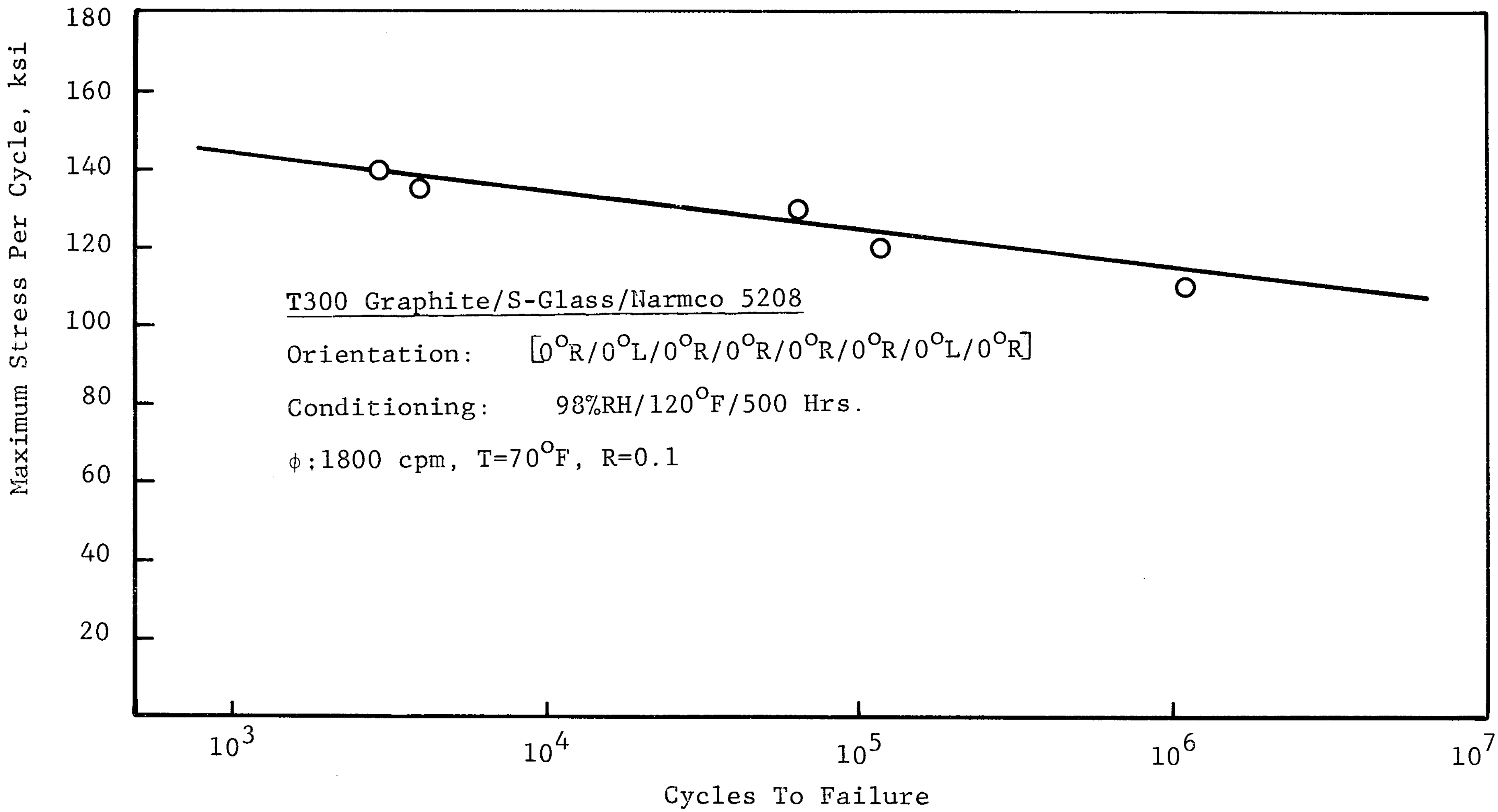


Fig.93 Fatigue S-N Curve For T300 Graphite/S-Glass/Narmco 5208 Hybrid Composite Tested at $R=0.1$, $\phi=30$ Hertz, and $T=70^{o}F$, After Conditioning At 98% RH, and $120^{o}F$ For 500 Hours

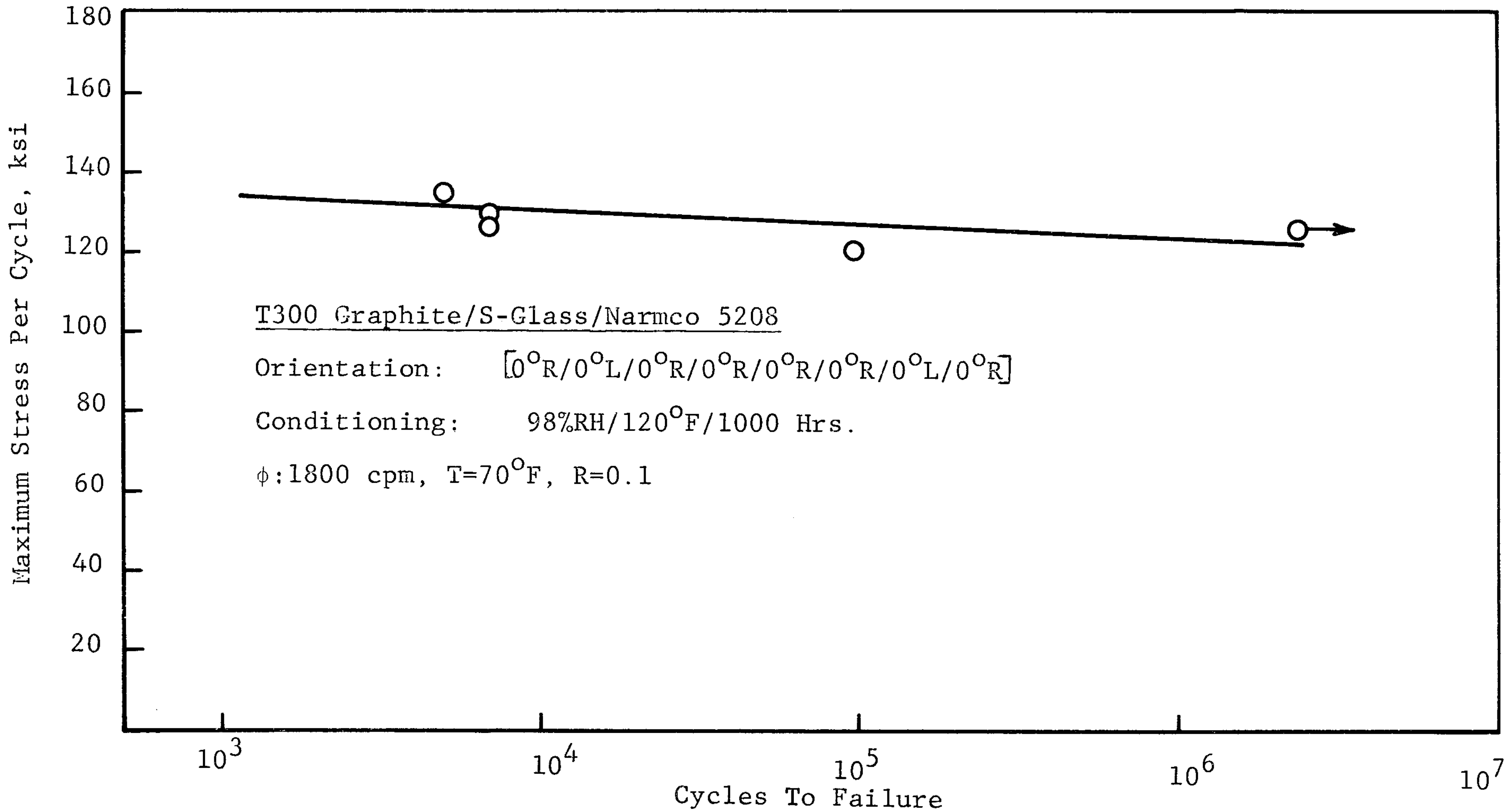


Fig. 94 Fatigue S-N Curve For T300 Graphite/S-Glass/Narmco 5208 Hybrid Composite Tested at R=0.1, ϕ=30 Hertz, and T=70°F, After Conditioning At 98% RH, and 120°F For 1000 Hours

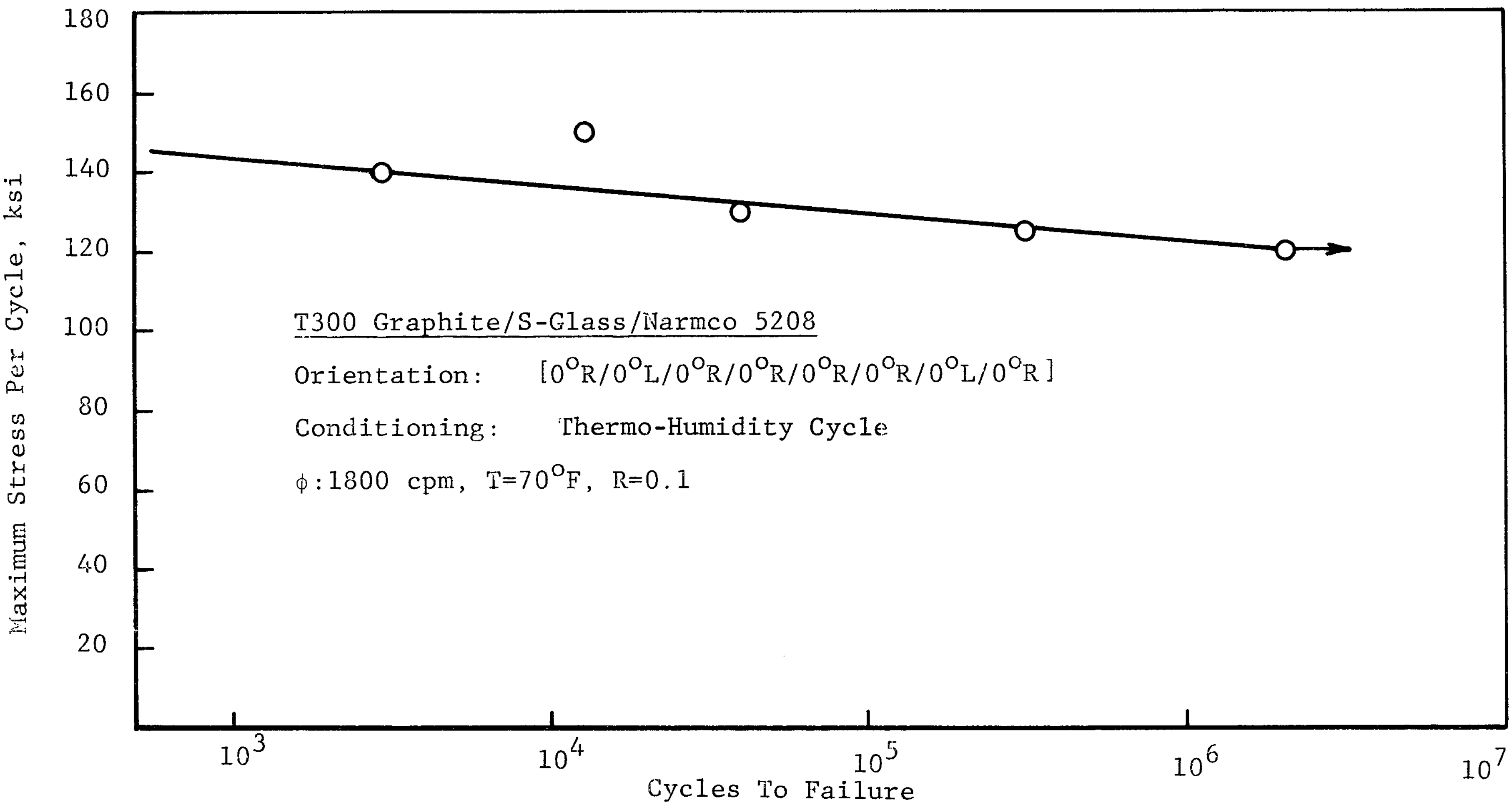


Fig. 95 Fatigue S-N Curve For T300 Graphite/S-Glass/Narmco 5208 Hybrid Tested at R=0.1, ϕ=30 Hertz and T=70^{o}F, Thermo-Humidity Cyclic Conditioning.

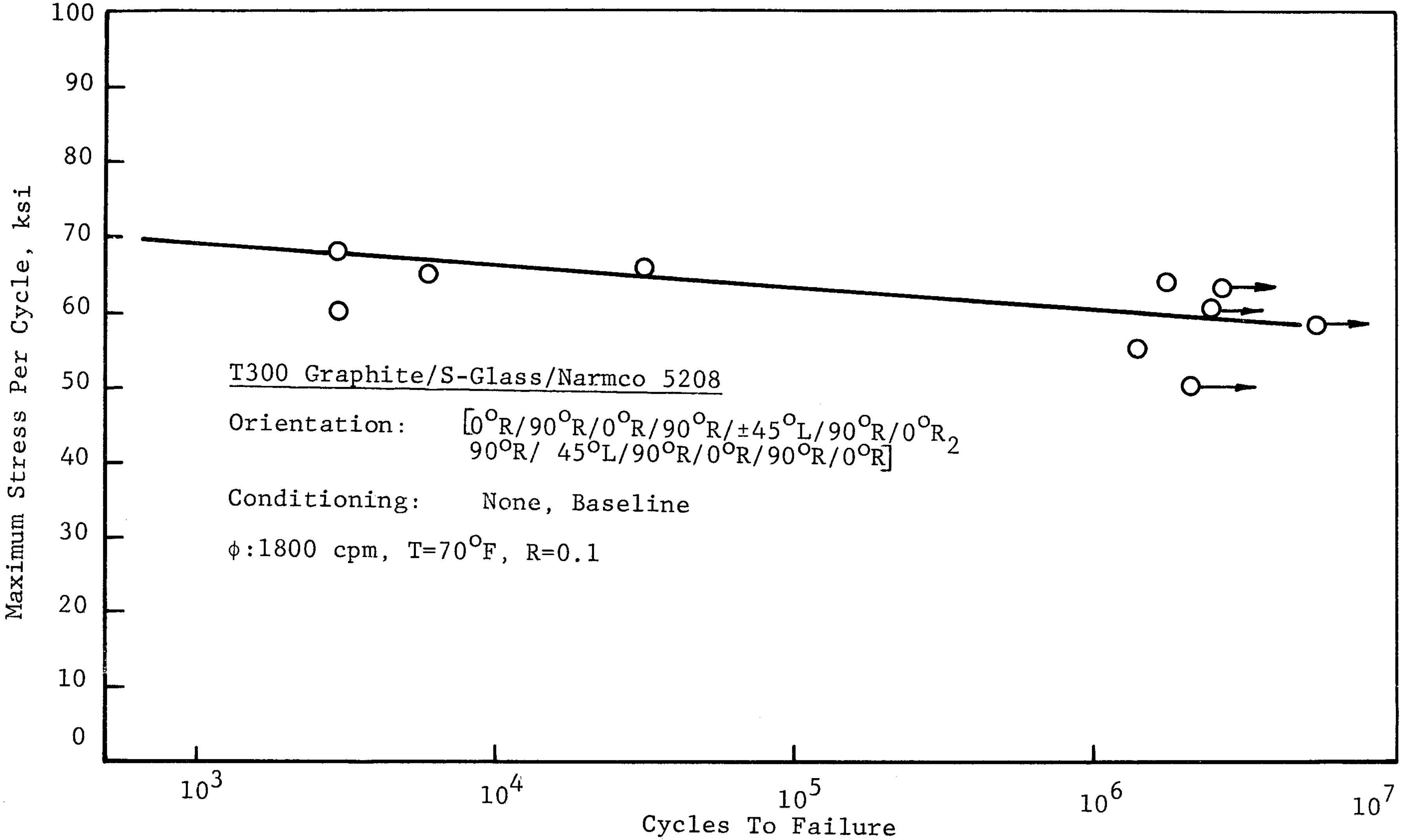


Fig. 96 Fatigue S-N Curve For S-Glass/T-300 Graphite/Narmco 5208 Hybrid Composite, Tested at R=0.1, ϕ=30 Hertz, and $T=70^oF$

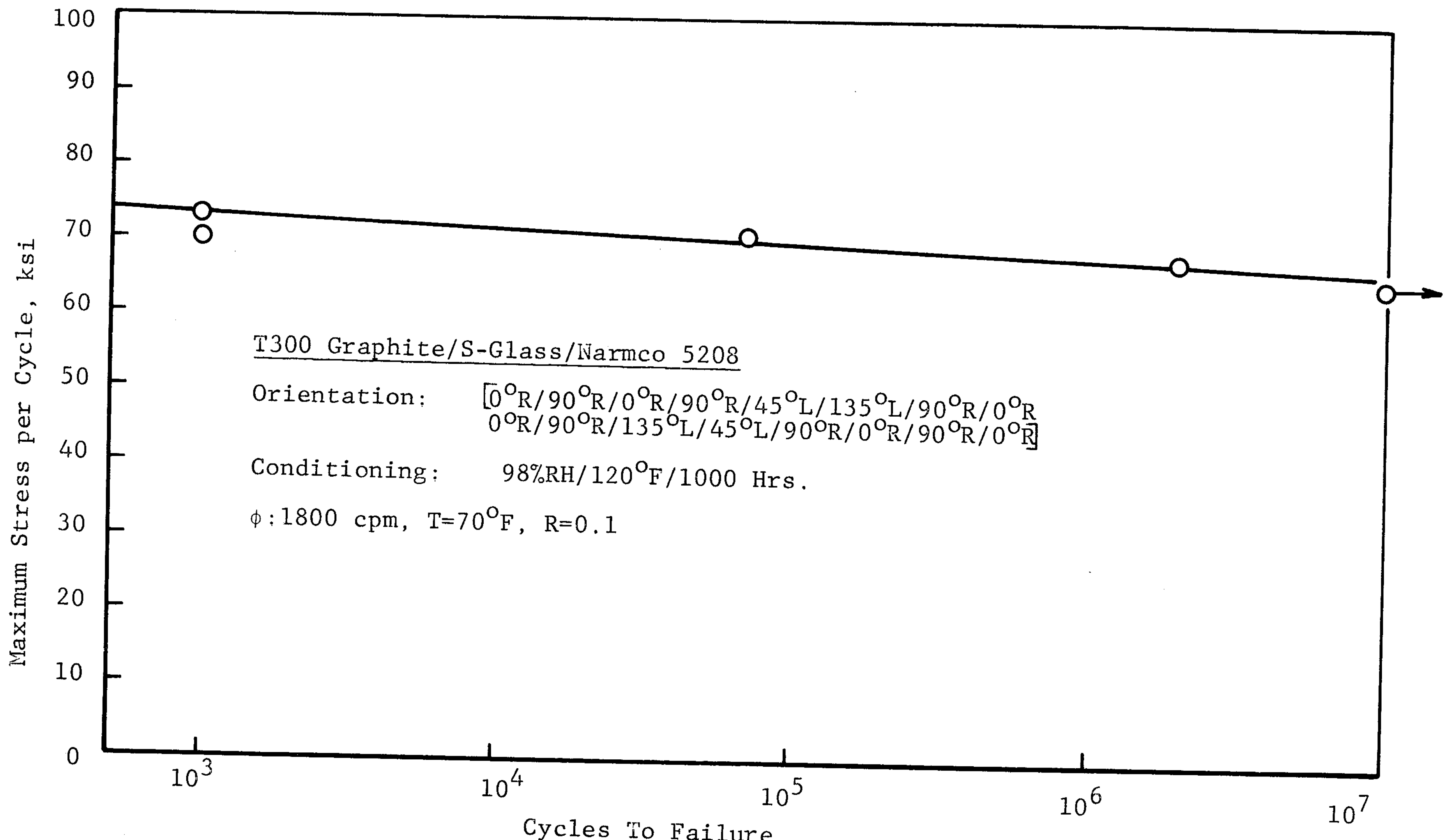


Fig. 97 Fatigue S-N Curve For T300 Graphite/S-Glass/Narmco 5208 Hybrid Composite Tested at R=0.1, ϕ=30 Hertz, and T=70°F, After Conditioning At 98% RH, and 120°F For 1000 Hours

APPENDIX III

INDIVIDUAL FATIQUE RESIDUAL
MECHANICAL PROPERTIES DATA

APPENDIX III

INDIVIDUAL FATIGUE RESIDUAL MECHANICAL PROPERTIES DATA

This appendix presents the schedule and individual test specimen results of the studies related to the determination of the residual mechanical properties of the basic and hybrid composites.

Table IX shows specimen orientation, prior conditioning, moisture weight gain (for the conditioned specimens), stress level, applied load cycles and the residual strength, elastic modulus and Poisson's ratio as determined for each specimen. Figure 98 through 109 present the entire stress-strain curves for each of the series of residual property determinations.

Table IX Summary of the Residual Mechanical Properties of Various Conventional and Hybrid Composites After Various Levels of Tension Stress Cycling.

Materials and Orientation	Prior Conditioning		Moisture Weight Gain	Stress Level	Cycles Applied	Residual Strength		Residual Elastic Modulus	Residual Poisson's Ratio
	Type	Duration	(%)	(ksi)	(Cycles)	(ksi)	($\%\sigma_{ult}$)	(msi)	(in/in)
$[0^{O}L_6]$	None	--	--	30	10,000	265	102	8.3	0.22
				30	50,000	249	96	8.6	0.24
				30	100,000	245	94	8.3	0.22
				30	500,000	269	103	--	--
				30	1,900,000	240	92	9.35	0.275
$[0^{O}L_6]$	98% RH	1000 Hrs.	1.05	30	10,000	212	81 *	7.5	0.25
			0.96	30	50,000	214	82 *	6.8	0.25
			1.08	30	100,000	206	79 *	6.9	0.23
			1.04	30	500,000	214	82 *	7.2	0.22
			0.79	30	1,800,000	191	73 *	7.2	0.23

*Expressed as a Percentage of the 70°F Dry Strength.

Table IX Summary of the Residual Mechanical Properties of Various Conventional and Hybrid Composites After Various Levels of Tension Stress Cycling.

Materials and Orientation	Prior Conditioning Type	Prior Conditioning Duration	Moisture Weight Gain (%)	Stress Level (ksi)	Cycles Applied (Cycles)	Residual Strength (ksi)	Residual Elastic Modulus (msi)	Residual Poisson's Ratio (in/in)
[$0^oL/\pm45^oL/90^oL_2/\mp45^oL/0^oL$]	None	--	--	13	10,000	62.0	3.85	0.26
	"	--	--	13	50,000	67.4	--	--
	"	--	--	13	100,000	68.2	3.80	0.28
	"	--	--	13	500,000	70.0	3.80	0.26
	"	--	--	13	1,700,000	57.0	3.10	0.18
[$0^oL/\pm45^oL/90^oL_2/\mp45^oL/0^oL$]	98% RH	1000 Hrs.	0.59	13	10,000	73.3	4.25	0.25
	"	"	0.63	13	50,000	68.1	3.87	0.25
	"	"	1.09	13	100,000	64.4	3.92	0.19
	"	"	0.99	13	500,000	76.6	4.15	0.22
	"	"	1.08	13	1,700,000	76.1	4.82	0.31

Table IX Summary of the Residual Mechanical Properties of Various Conventional and Hybrid Composites After Various Levels of Tension Stress Cycling.

Materials and Orientation	Prior Conditioning		Moisture Weight Gain	Stress Level	Cycles Applied	Residual Strength		Residual Elastic Modulus	Residual Poisson's Ratio
	Type	Duration	(%)	(ksi)	(Cycles)	(ksi)	($\%\sigma_{ult}$)	(msi)	(in/in)
$[0^o R_6]$	None	--	--	122	10,000	215	99	20.7	0.21
	"	--	--	122	50,000	223	102	22.3	0.27
	"	--	--	122	100,000	211	97	21.0	0.21
	"	--	--	122	500,000	221	101	21.0	0.25
	"	--	--	122	1,600,000	204	94	21.7	0.25
$[0^o R_6]$	98% RH	1000 Hrs.	1.18	122	10,000	176	91*	20.0	0.28
	"	"	1.26	122	50,000	238	123*	21.0	0.22
	"	"	1.19	122	100,000	228	118*	21.4	0.27
	"	"	1.22	122	500,000	238	123*	19.5	0.28
	"	"	1.25	122	1,600,000	199	103*	22.6	0.32

*Based on the value of 193 ksi for T300 Graphite/Narmco 5208 after Exposure to 98% RH for 1000 Hours.

Table IX Summary of the Residual Mechanical Properties of Various Conventional and Hybrid Composites After Various Levels of Tension Stress Cycling.

Materials and Orientation	Prior Conditioning Type	Prior Conditioning Duration	Moisture Weight Gain (%)	Stress Level (ksi)	Cycles Applied (Cycles)	Residual Strength (ksi)	Residual Elastic Modulus (msi)	Residual Poisson's Ratio (in/in)
$[0^oR/\pm45^oR/90^oR_2/\mp45^oR/0^oR]$	None	--	--	50	10,000	70.6	6.1	0.41
		--	--	50	50,000	57.9	6.6	0.34
		--	--	50	100,000	61.2	6.7	0.34
		--	--	50	423,000*	--	--	--
		--	--	50	500,000	57.4	6.9	0.78
$[0^oR/\pm45^oR/90^oR_2/\mp45^oR/0^oR]$	98% RH	1000 Hrs.	1.27	50	10,000	67.1	7.0	0.32
	"	"	1.14	50	50,000	59.3	6.5	0.67
	"	"	1.01	50	100,000	59.6	6.8	0.61
	"	"	1.16	50	179,000*	--	--	--
	"	"	1.29	50	500,000	57.3	6.7	0.68

*Specimen Failed During Stress Cycling

Table IX Summary of the Residual Mechanical Properties of Various Conventional and Hybrid Composites After Various Levels of Tension Stress Cycling.

Materials and Orientation	Prior Conditioning		Moisture Weight Gain	Stress Level	Cycles Applied	Residual Strength	Residual Elastic Modulus	Residual Poisson's Ratio
	Type	Duration	(%)	(ksi)	(Cycles)	(ksi)	(msi)	(in/in)
$[0^oR/0^oL/0^oR/0^oL_2/0^oR/0^oL/0^oR]$	None	--	--	85	10,000	153	15.9	0.30
	"	--	--	85	50,000	172	15.4	0.28
	"	--	--	85	100,000	165	15.1	0.27
	"	--	--	85	500,000	164	13.7	0.33
	"	--	--	85	1,660,000	161	14.6	0.26
$[0^oR/0^oL/0^oR/0^oL_2/0^oR/0^oL/0^oR]$	98% RH	1000 Hrs.	0.90	85	10,000	161	15.2	0.26
	"	"	0.97	85	50,000	156	14.5	0.25
	"	"	0.84	85	100,000	167	15.7	0.25
	"	"	0.91	85	500,000	163	15.3	0.27
	"	"	0.95	85	1,700,000	159	15.1	0.26

Table IX Summary of the Residual Mechanical Properties of Various Conventional and Hybrid Composites After Various Levels of Tension Stress Cycling.

Materials and Orientation	Prior Conditioning		Moisture Weight Gain	Stress Level	Cycles Applied	Residual Strength	Residual Elastic Modulus	Residual Poisson's Ratio
	Type	Duration	(%)	(ksi)	(Cycles)	(ksi)	(msi)	(in/in)
$[0^\circ R/90^\circ R/\pm 45^\circ L/90^\circ R/$ $0^\circ R_2/90^\circ R/\mp 45^\circ L/90^\circ R/0^\circ R]$	None	--	--	100	10,000	185	--	--
	"	--	--	100	50,000	161	14.0	0.26
	"	--	--	100	100,000	156	14.7	0.23
	"	--	--	100	500,000	144	14.3	0.27
	"	--	--	100	1,000,000	139	15.2	0.18
$[0^\circ R/90^\circ R/\pm 45^\circ L/90^\circ R/$ $0^\circ R_2/90^\circ R/\mp 45^\circ L/90^\circ R/0^\circ R]$	98% RH	1000 Hrs.	1.36	100	10,000	187	16.8	0.23
	"	"	1.30	100	50,000	176	17.1	0.21
	"	"	1.11	100	100,000	183	16.6	0.29
	"	"	1.36	100	500,000	156	16.2	0.24
	"	"	1.24	100	2,000,000	161	15.7	0.25

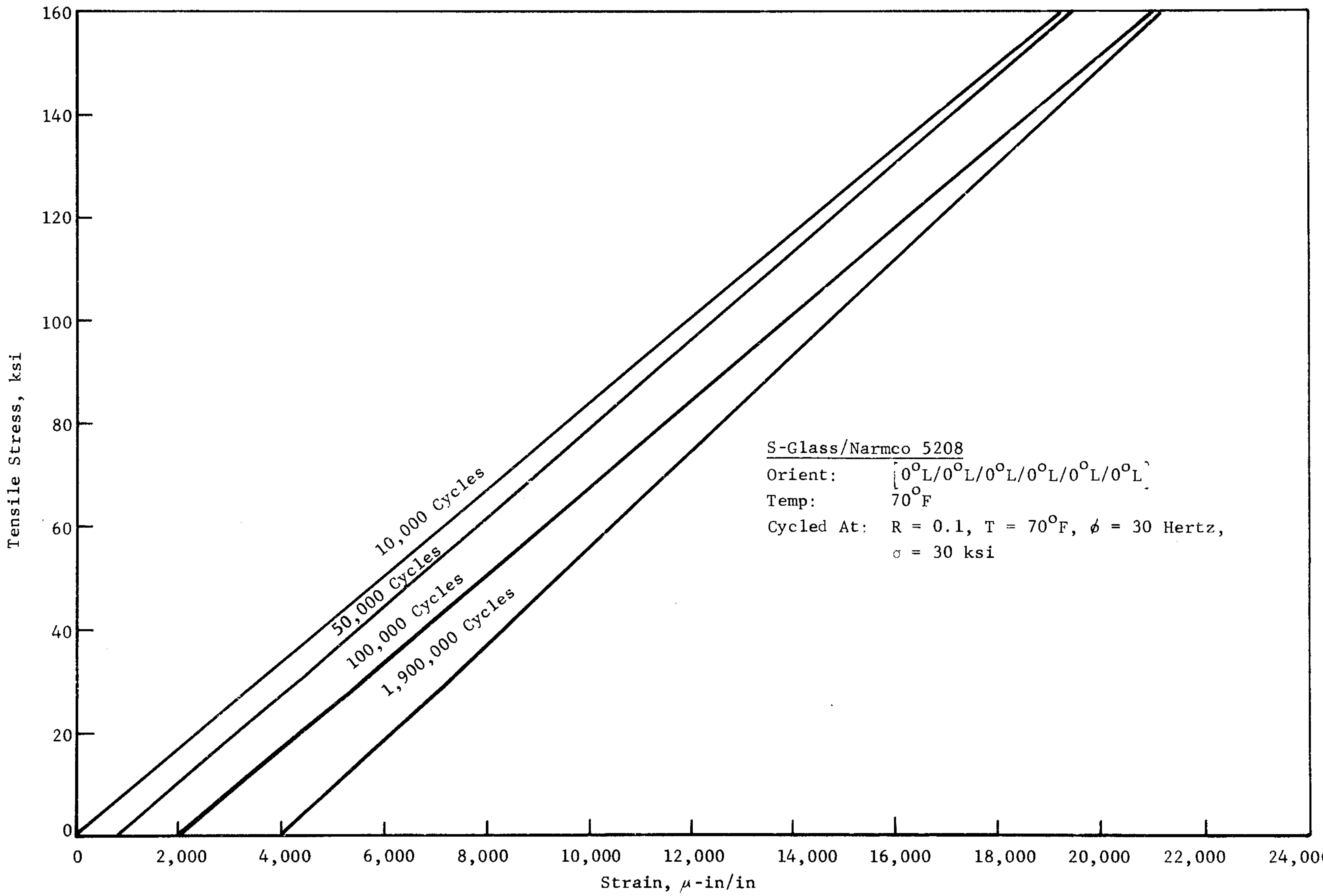


Fig. 98 Stress-Strain Curves for S-Glass/Narmco 5208 Composites After Various Stress Cycles

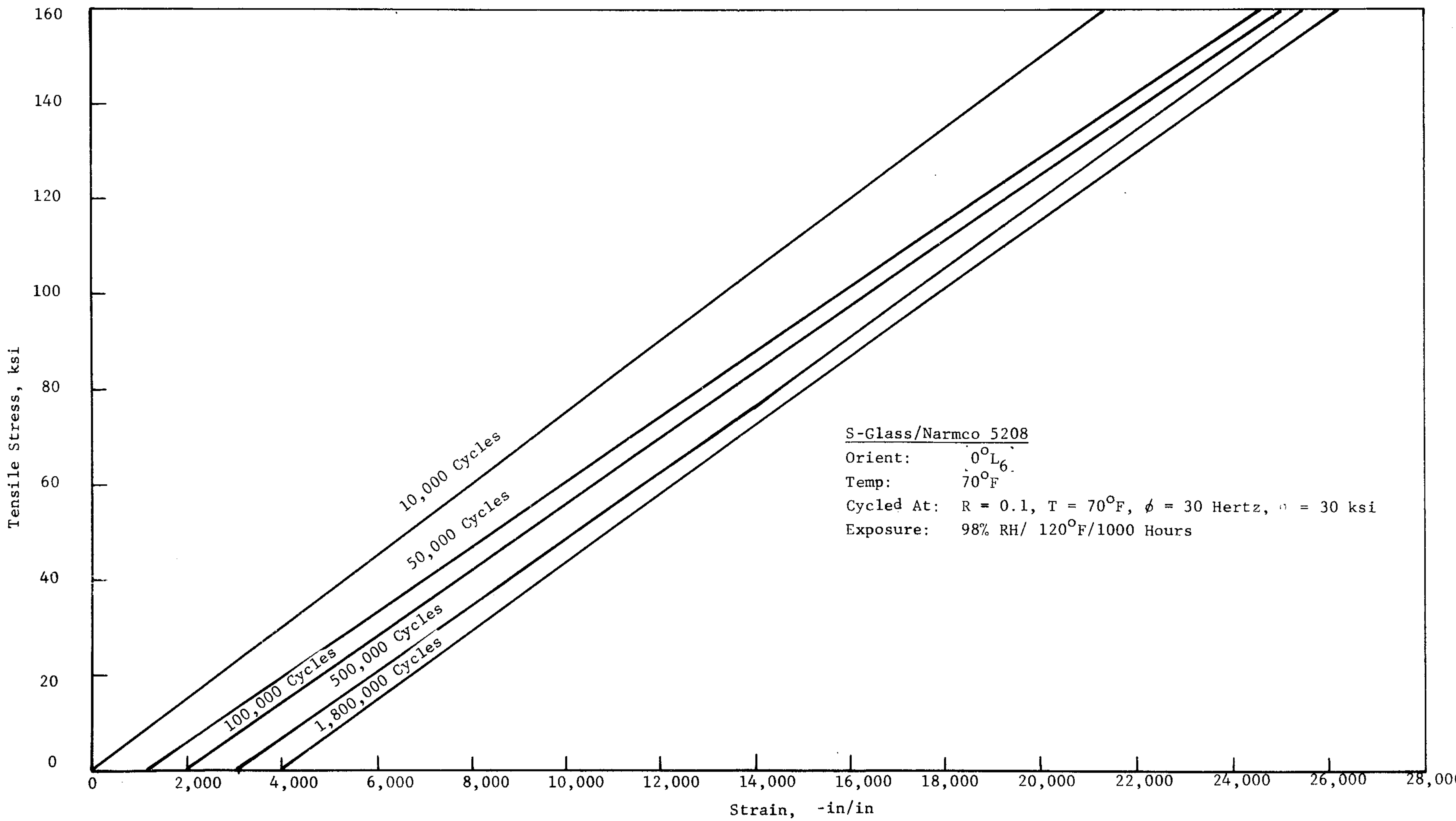


Fig. 99 Stress-Strain Curves for S-Glass/Narmco 5208 Composites After Various Stress Cycles and Exposure to 98% RH and $120^{\circ}F$ for 1,000 Hours

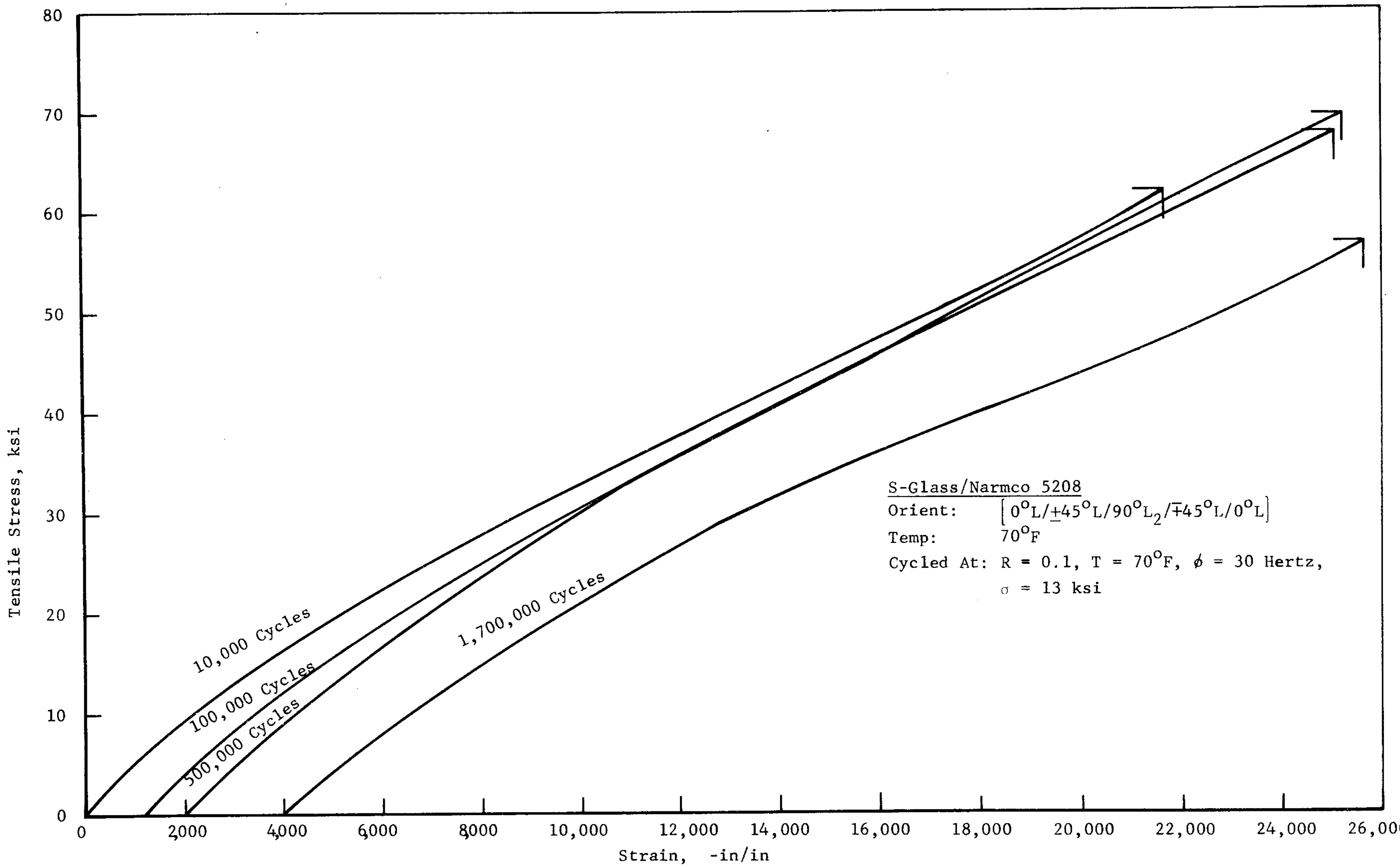


Fig. 100 Stress-Strain Curves for S-Glass/Narmco 5208 Composites After Various Stress Cycles

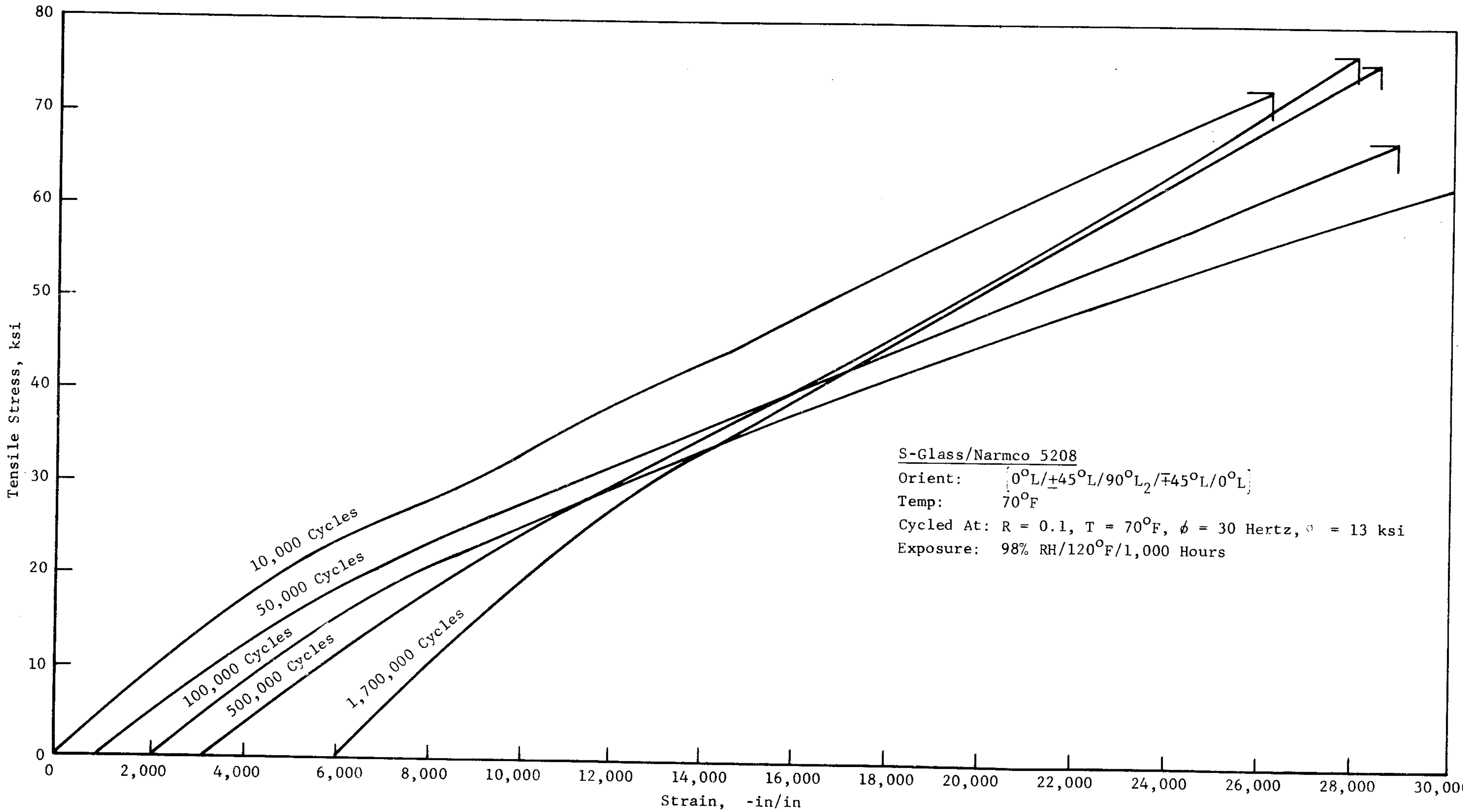


Fig. 101 Stress-Strain Curves for S-Glass/Narmco 5208 Composites After Various Stress Cycles and Exposure to 98% RH and 120^oF for 1000 Hours

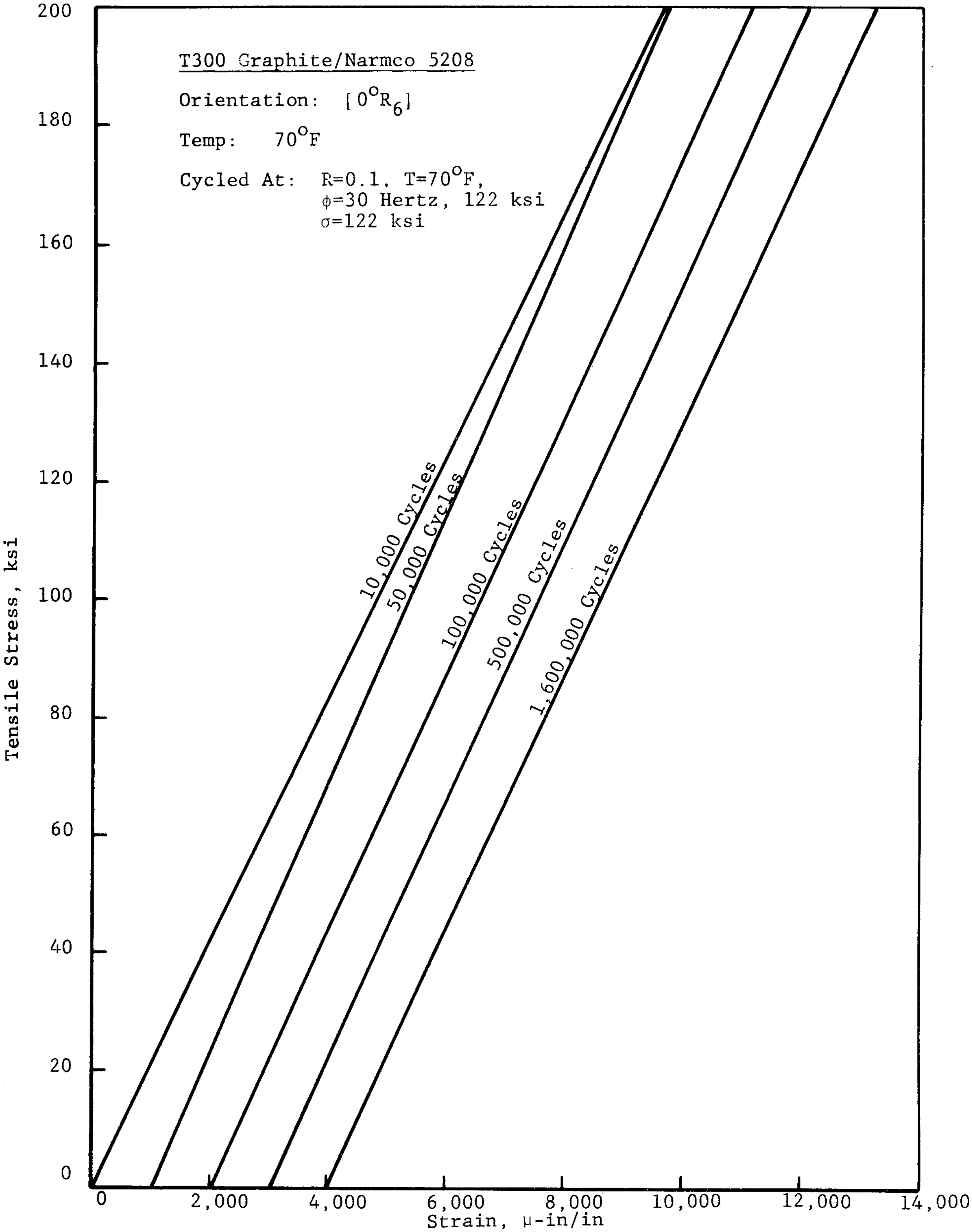


Fig. 102 Stress-Strain Curves For T-300 Graphite/Narmco 5208 Composite After Various Stress Cycles

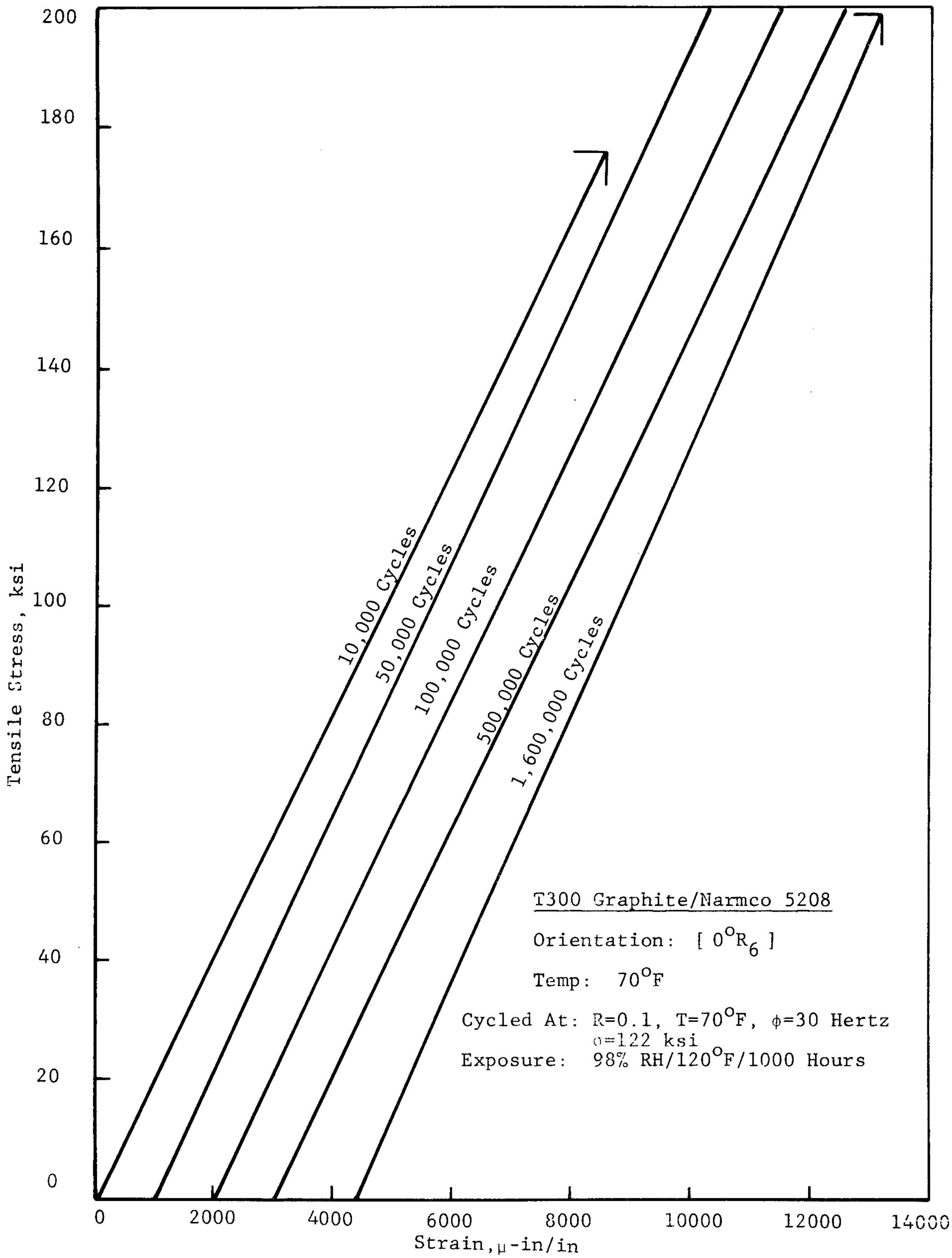


Fig.103 Stress-Strain Curves For T-300/Graphite/Narmco 5208 Composites After Various Stress Cycles And Exposure To 98% RH and $120^{O}F$ For 1000 Hours

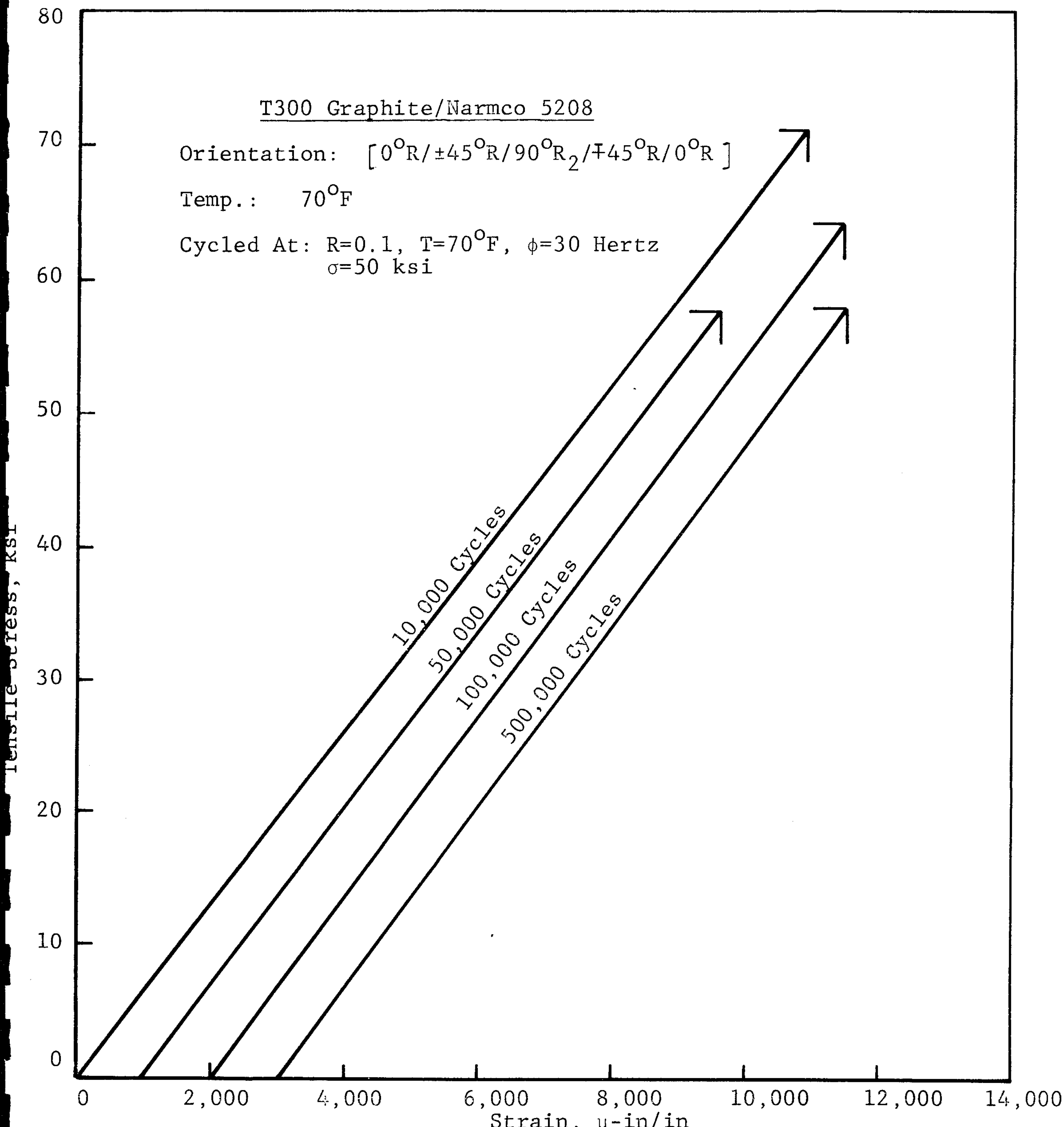


Fig. 104 Stress-Strain Curves For T-300 Graphite/Narmco 5208 Composite After Various Stress Cycles

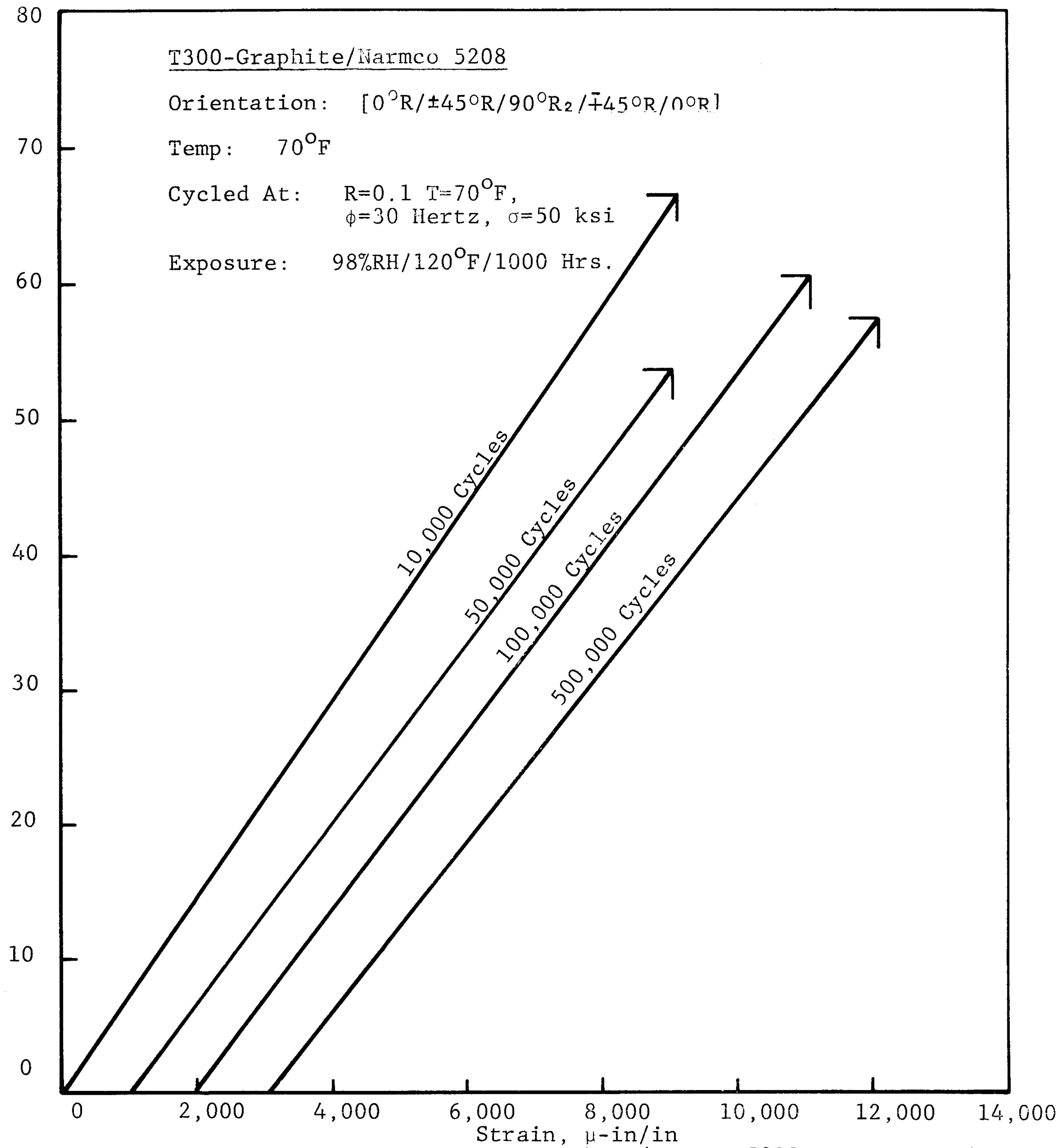


Fig.105 Stress-Strain Curves For T300 Graphite/Narmco 5208 Composite After Various Stress Cycles And Exposure To 98%RH and 120°F For 1000 Hours

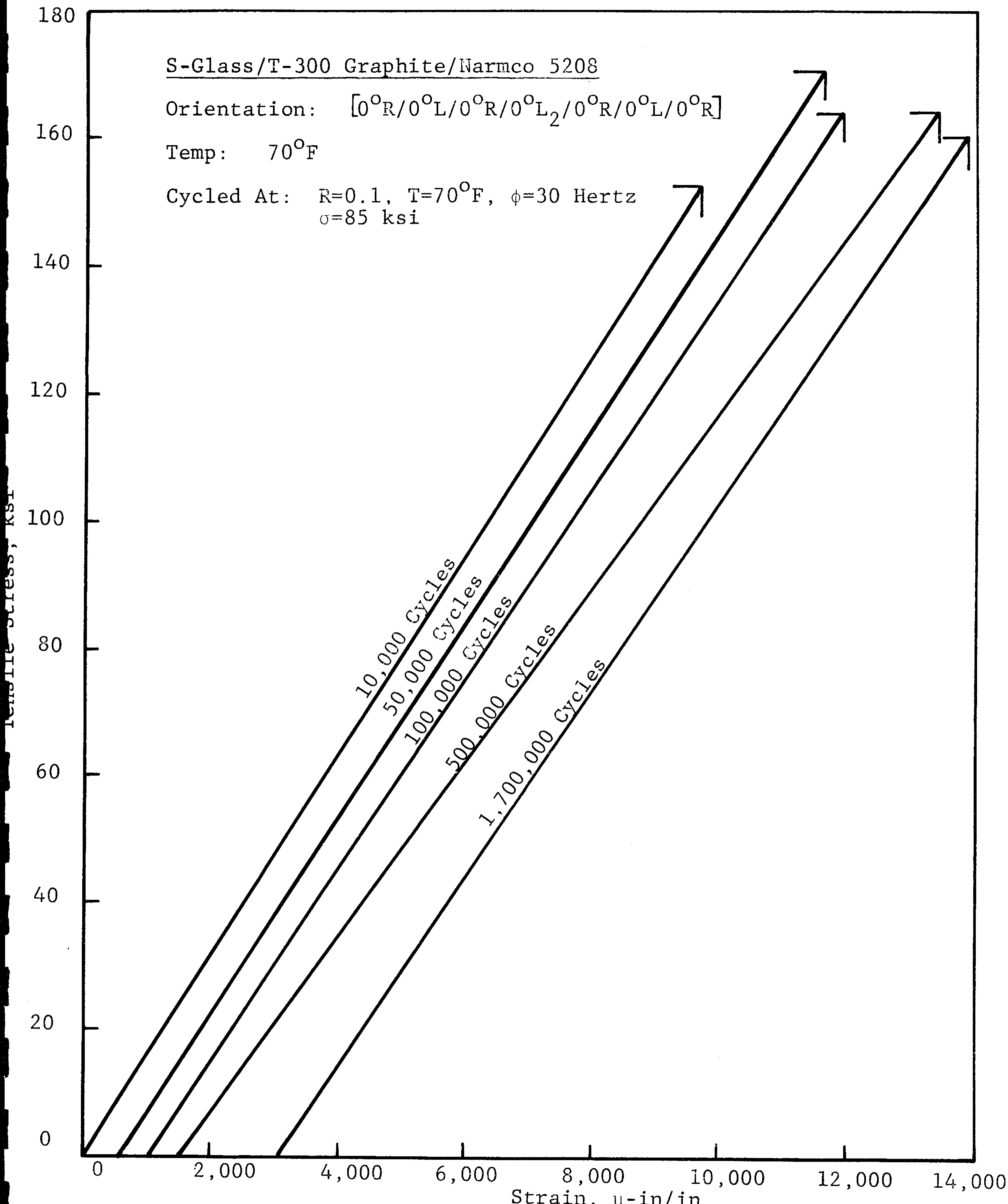


Fig.106 Stress-Strain Curves For S-Glass/T-300 Graphite/Narmco 5208 Hybrid Composites After Various Stress Cycles

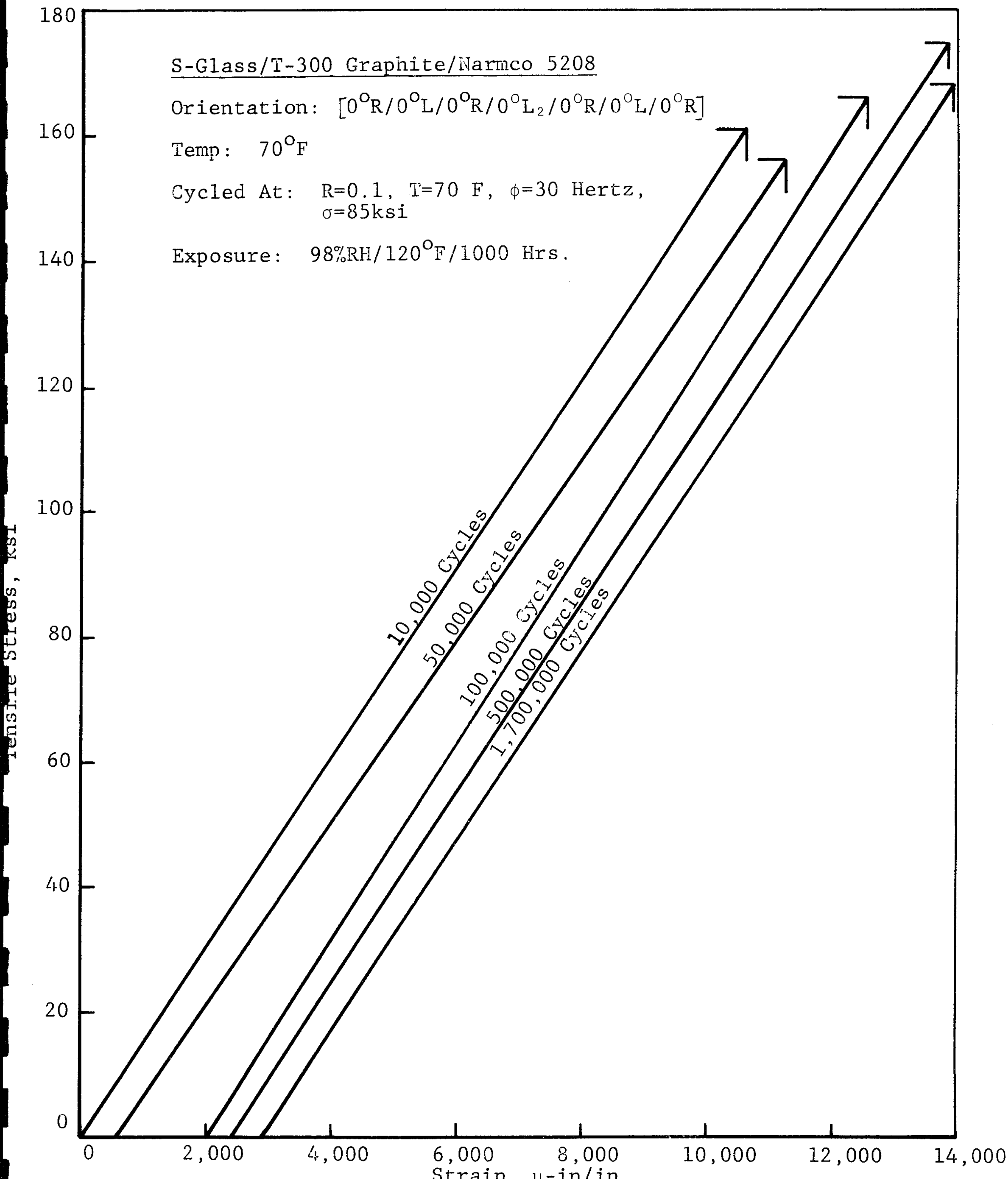


Figure 107 Stress Strain Curves for S-Glass/T-300 Graphite/Narmco 5208 Hybrid Composites after Various Stress Cycles and Exposure to 98% RH and 120°F for 1000 Hours.

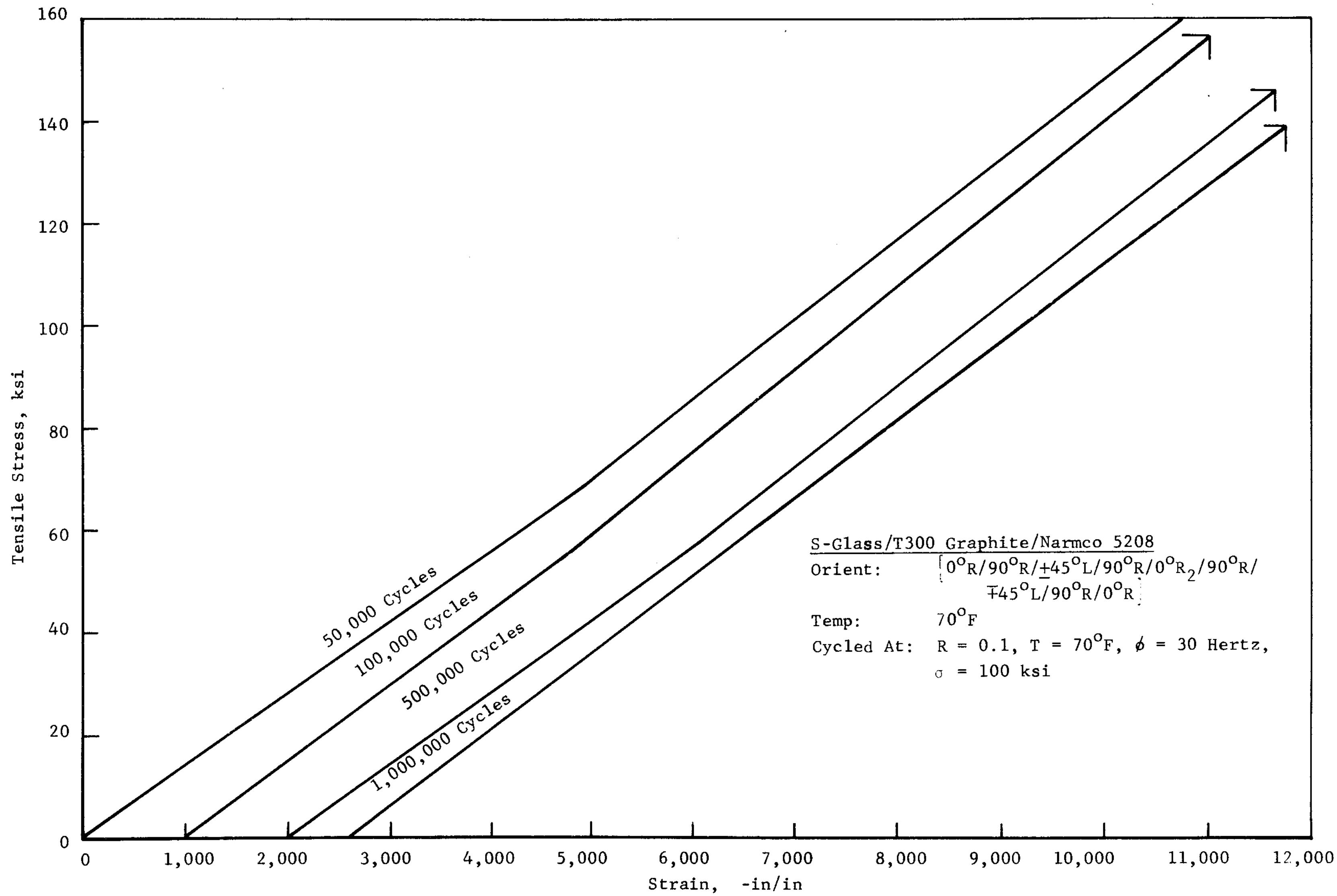


Fig. 108 Stress-Strain Curves for S-Glass/T300 Graphite/Narmco 5208 Hybrid Composites After Various Stress Cycles

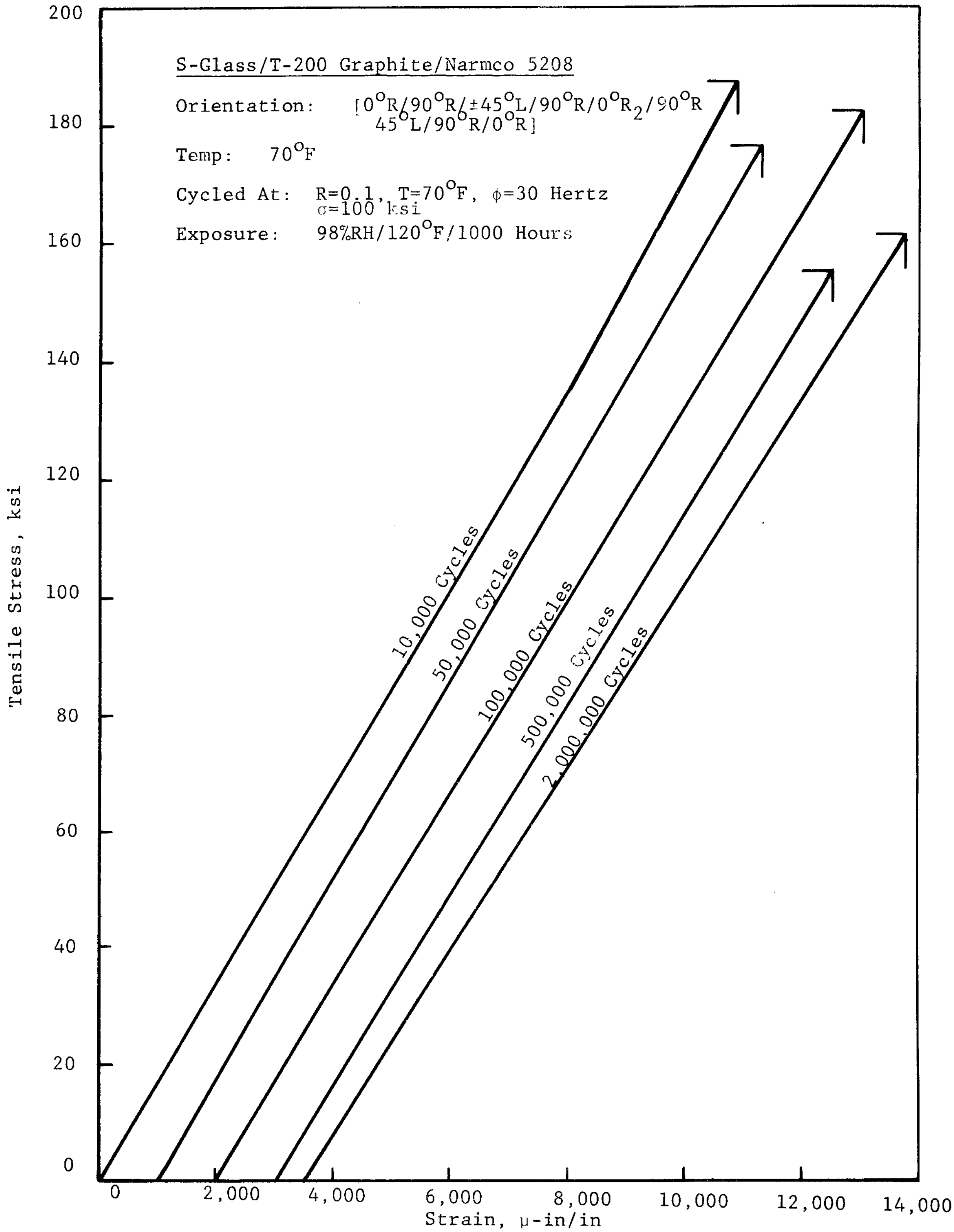


Fig.109 Stress-Strain Curves For S-Glass/T-300 Graphite/Narmco 5208 Hybrid Composites After Various Stress-Cycles And Exposure To 98%RH and 120°F For 1000 Hours

APPENDIX IV

Individual Data for Lateral Impact of Hybrid Composites

APPENDIX IV

INDIVIDUAL DATA FOR LATERAL IMPACT OF HYBRID COMPOSITES

This section contains the individual specimen data for all lateral impact testing. Basic and hybrid composite materials, ply arrangements, specimen thicknesses, moisture weight gain, prior conditioning and energy to fracture are shown.

Some specimens did not completely fracture into two pieces after impact but retained some integrity, often a single or at most two plies remaining intact. The energy necessary to deflect the partially broken sample and push it through the opening in the Charpy base support was determined statically using the Instron and subtracted from the apparent energy to fracture, thus producing the last calculated values of the true energy to fracture. This data is shown in the final column of Table X.

TABLE X. INDIVIDUAL SPECIMEN DATA FOR LATERAL IMPACT TESTS

Specimen Number	Thickness (Plies)/(In.)	Material and Orientation	Prior Conditioning Type	Prior Conditioning Duration	Moisture Weight Gain %	Energy to Fracture (ft.-lb.)	Type of Failure	Energy Req'd To Push Spec Through Fixture (in.-lb.)	Corrected Energy To Fracture (in.-lbs.)
1	6 /0.033	$[0°R_6]$	None	-	-	3.50	complete	-	42
2	" /0.033	"	"	"	"	3.50	complete	"	42
3	" /0.033	"	"	"	"	3.75	complete	"	45
4	" /0.032	"	"	"	"	3.75	complete		45
5	" /0.033	"	"	"	"	3.50	partial		41
6	" /0.032	"	"	"	"	3.75	partial		44
7	" /0.033	"	"	"	"	3.50	complete	"	42
8	" /0.033	"	"	"	"	3.50	partial		41
9	" /0.033	"	"	"	"	4.00	complete	"	48
11	8 /0.044	$[0°R_8]$	98% RH	500 hrs	0.76	4.00	complete	"	48
12	" /0.044	"	"	"	0.75	4.25	complete	"	51
13	" /0.044	"	"	"	0.79	4.25	complete	"	51
14	" /0.045	"	"	"	0.85	4.25	complete	"	51
15	" /0.043	"	"	"	0.73	4.50	complete	"	54
16	" /0.045	"	"	1000 hrs	0.95	4.75	complete	"	57
17	" /0.044	"	"	"	0.99	5.00	complete	"	60
18	" /0.043	"	"	"	0.99	4.50	complete	"	54
19	" /0.044	"	"	"	1.93	4.50	partial		53
20	" /0.045	"	"	"	1.02	4.75	complete	"	57
21	" /0.043	"	Thermo Humidity Cycle		0.57	5.00	complete	"	60
22	" /0.044	"	"	" "	0.84	5.00	complete	"	60
23	" /0.045	"	"	" "	0.82	4.75	complete	"	57
24	" /0.045	"	"	" "	0.85	5.00	complete	"	60

TABLE X. INDIVIDUAL SPECIMEN DATA FOR LATERAL IMPACT TESTS

Specimen Number	Thickness (Plies)/(In.)	Material and Orientation	Prior Conditioning Type	Prior Conditioning Duration	Moisture Weight Gain %	Energy to Fracture (ft.-lb.)	Type of Failure	Energy Req'd to Push Spec Through Fixture (in.-lb.)	Corrected Energy to Fracture (in.-lb.)
1	8 /0.047	$[0^\circ R/90^\circ R/0^\circ R/90^\circ R_2/0^\circ R/90^\circ R/0^\circ R]$	None	-	-	2.25	complete	-	27
2	" /0.045	"	"	"	"	2.25	complete	"	27
3	" /0.044	"	"	"	"	3.0	complete	"	36
4	" /0.044	"	"	"	"	2.75	complete	"	33
5	" /0.047	"	"	"	"	2.25	complete	"	27
6	" /0.045	"	"	"	"	2.50	complete	"	30
7	" /0.047	"	"	"	"	2.50	complete	"	30
8	" /0.047	"	"	"	"	2.50	complete	"	30
9	" /0.048	"	"	"	"	2.50	complete	"	30
10	" /0.045	"	"	"	"	2.75	complete	"	33
11	" /0.044	"	98% RH	500 hrs	0.30	2.75	complete	"	33
12	" /0.045	"	"	"	0.67	2.75	complete	"	33
13	" /0.043	"	"	"	0.60	2.75	complete	"	33
14	" /0.044	"	"	"	0.64	3.0	complete	"	36
15	" /0.044	"	"	"	0.56	2.75	complete	"	33
16	" /0.047	"	"	1000 hrs	0.86	3.50	complete	"	42
17	" /0.047	"	"	"	0.87	3.50	complete	"	42
18	" /0.045	"	"	"	0.84	3.50	complete	"	42
19	" /0.047	"	"	"	0.86	3.75	complete	"	45
20	" /0.046	"	"	"	0.82	3.75	complete	"	45
21	" /0.044	"	Thermo Humidity	Cycle	1.09	3.25	partial	0.1	39
22	" /0.044	"	"	" "	1.15	3.0	partial	0.1	36
23	" /0.045	"	"	" "	0.98	4.25	complete	-	51
24	" /0.044	"	"	" "	1.08	3.50	complete	"	42
25	" /0.043	"	"	" "	1.01	3.25	complete	"	39

TABLE X. INDIVIDUAL SPECIMEN DATA FOR LATERAL IMPACT TESTS

Specimen Number	Thickness (Plies)/(In.)	Material and Orientation	Prior Conditioning Type	Prior Conditioning Duration	Moisture Weight Gain %	Energy to Fracture (ft.-lb.)	Type of Failure	Energy Req'd to Push Spec Through Fixture (in.-lb.)	Corrected Energy to Fracture (in.-lb.)
1	8 /0.045	[0°R/90°L/0°L/90°R_2/0°L/90°L/0°R]	None	-	-	6.00	Partial	13.8	58
2	/0.047	"	"	"	"	5.50	Partial	"	52
3	" /0.045	"	"	"	"	5.25	Partial	"	49
4	" /0.045	"	"	"	"	6.00	Partial	"	52
5	" /0.044	"	"	"	"	4.75	Partial	"	43
6	" /0.044	"	98% RH	500 hrs	0.32	3.50	Partial	17.6	24
7	" /0.045	"	"	"	0.33	3.75	Partial	"	27
8	" /0.049	"	"	"	0.36	4.75	Partial	"	39
9	" /0.047	"	"	"	0.24	4.75	Partial	"	39
10	" /0.047	"	"	"	0.35	5.25	Partial	"	48
11	" /0.044	"	"	1000 hrs	0.26	8.00	Partial	26.2	70
12	" /0.045	"	"	"	0.27	7.25	Partial	"	61
13	" /0.044	"	"	"	0.30	7.25	Partial	"	61
14	" /0.044	"	"	"	0.24	7.75	Partial	"	67
15	" /0.045	"	"	"	0.25	7.50	Partial	"	63
16	" /0.044	"	Thermo Humidity Cycle		0.93	4.00	Partial	10.8	37
17	" /0.045	"	" " "		0.21	3.75	Partial	"	34
18	" /0.044	"	" " "		0.31	3.75	Partial	"	34
19	" /0.043	"	" " "		0.41	5.00	Partial	"	49
20	" /0.043	"	" " "		-	3.50	Partial	"	31

TABLE X. INDIVIDUAL SPECIMEN DATA FOR LATERAL IMPACT TESTS

Specimen Number	Thickness (Plies)/(In.)	Material and Orientation	Prior Conditioning Type	Prior Conditioning Duration	Moisture Weight Gain %	Energy to Fracture (ft.-lb.)	Type of Failure	Energy Req'd to Push Spec Through Fixture (in.-lb.)	Corrected Energy to Fracture (in.-lb.)
1	8 /0.046	$[0°R/+45°L/90°R_2/+45°L/0°R]$	98% RH	500 hrs	0.60	5.25	Partial	9.5	53
2	" /0.043	"	"	"	0.30	4.75	Partial	"	47
3	" /0.045	"	"	"	0.72	5.00	Partial	"	50
4	" /0.046	"	"	"	0.52	5.25	Partial	"	53
5	" /0.046	"	"	"	-	-	Partial	"	-
6	" /0.050	"	"	1000 hrs	0.60	6.00	Partial	30.1	42
7	" /0.051	"	"	"	0.52	7.00	Partial	"	54
8	" /0.046	"	"	"	0.86	6.25	Partial	"	45
9	" /0.044	"	"	"	0.55	6.00	Partial	"	42
10	" /0.045	"	"	"	0.81	6.50	Partial	"	48
11	" /0.046	"	Thermo Humidity Cycle		0.74	5.50	Partial	30.2	36
12	" /0.044	"	" " "		0.53	5.75	Partial	"	39
13	" /0.047	"	" " "		0.67	5.75	Partial	"	39
14	" /0.046	"	" " "		0.77	6.25	Partial	"	45
15	" /0.045	"	" " "		0.72	6.50	Partial	"	48

TABLE X. INDIVIDUAL SPECIMEN DATA FOR LATERAL IMPACT TESTS

Specimen Number	Thickness (Plies)/(In.)	Material and Orientation	Prior Conditioning Type	Prior Conditioning Duration	Moisture Weight Gain %	Energy to Failure (ft.-lb.)	Type of Fracture	Energy Req'd to Push Spec Through Fixture (in.-lb.)	Corrected Energy to Fracture (in.-lbs.)
1	12	[0°R/90°R/+45°L/90°R/0°R$_2$/90°R/∓45°L/90°R/0°R]	None	-	-	22.00	Partial	21.5	242
2	"	"	"	"	"	30.00	Partial	"	338
3	"	"	"	"	"	18.00	Partial	"	194
4	"	"	"	"	"	17.00	Partial	"	182
5	"	"	"	"	"	20.00	Partial	"	218
6	" /0.072	"	98% RH	500 hrs	0.28	12.50	Partial	24.9	125
7	" /0.070	"	"	"	0.24	14.75	Partial	"	152
8	" /0.071	"	"	"	0.33	14.00	Partial	"	144
9	" /0.071	"	"	"	0.28	14.00	Partial	"	144
10	" /0.071	"	"	"	0.20	15.00	Partial	"	155
11	" /0.070	"	"	1000 hrs	2.19	13.25	Partial	11.8	147
12	" /0.073	"	"	"	2.06	13.50	Partial	"	150
13	" /0.066	"	"	"	1.16	11.25	Partial	"	123
14	" /0.073	"	"	"	1.48	12.25	Partial	"	135
15	" /0.070	"	"	"	1.61	12.25	Partial	"	135
16	" /0.072	"	Thermo Humidity Cycle		-	11.75	Partial	55.4	86
17	" /0.071	"	"	" "	"	11.80	Partial	"	86
18	" /0.071	"	"	" "	"	12.25	Partial	"	41
19	" /0.072	"	"	" "	"	11.75	Partial	"	86
20	" /0.069	"	"	" "	"	12.00	Partial	"	86

TABLE X. INDIVIDUAL SPECIMEN DATA FOR LATERAL IMPACT TESTS

Specimen Number	Thickness (Plies)/(In.)		Material and Orientation	Prior Conditioning		Moisture Weight Gain %	Energy to Fracture (ft.-lb.)	Type of Failure	Energy Req'd to Push Spec Through Fixture (in.-lb.)	Corrected Energy to Fracture (in.-lb.)
				Type	Duration					
1	8	/0.044	[0°R/0°L/0°R_4/0°1/0°R]	None	-	-	7.00	complete	-	84
2	"	/0.045	"	"	"	"	6.50	complete	"	78
3	"	/0.046	"	"	"	"	6.00	complete	"	72
4	"	/0.046	"	"	"	"	6.75	complete	"	81
5	"	/0.045	"	"	"	"	6.75	complete	"	81
6	"	/0.043	"	98% RH	500 hrs	0.33	5.00	complete	"	60
7	"	/0.045	"	"	"	0.33	5.25	complete	"	63
8	"	/0.043	"	"	"	0.39	4.75	complete	"	57
9	"	/0.045	"	"	"	0.41	6.00	complete	"	72
10	"	/0.046	"	"	"	0.23	6.75	complete	"	81
11	"	/0.046	"	"	1000 hrs	0.11	5.50	complete	"	66
12	"	/0.044	"	"	"	0.10	5.25	complete	"	63
13	"	/0.046	"	"	"	0.08	6.00	complete	"	72
14	"	/0.045	"	"	"	0.14	5.00	complete	"	60
15	"	/0.043	"	"	"	0.14	5.00	complete	"	60
16	"	/0.044	"	Thermo Humidity Cycle		-	5.00	complete	"	60
17	"	/0.044	"	" "	"	"	5.50	complete	"	66
18	"	/0.046	"	" "	"	"	6.00	complete	"	72
19	"	/0.047	"	" "	"	"	6.00	complete	"	72
20	"	/0.045	"	" "	"	"	5.50	complete	"	66

TABLE X. INDIVIDUAL SPECIMEN DATA FOR LATERAL IMPACT TESTS

Specimen Number	Thickness (Plies/(In.)	Material and Orientation	Prior Conditioning Type	Prior Conditioning Duration	Moisture Weight Gain %	Energy to Failure (ft.-lb.)	Type of Fracture	Energy Req'd to Push Spec Through Fixture (in.-lb.)	Corrected Energy to Fracture (in.-lbs.)
1	8 /0.044	[0°R/90°R/0°L/90°R_2/0°L/90°R/0°R]	None	-	-	2.25	partial	18.4	9
2	" /0.044	"	"	"	"	1.75	partial	"	3
3	" /0.045	"	"	"	"	2.00	partial	"	6
4	" /0.046	"	"	"	"	1.75	partial	"	3
5	" /0.047	"	"	"	"	2.00	partial	"	6
6	" /0.046	"	98% RH	500 hrs	0.53	0.50	partial	11.4	5
7	" /0.047	"	"	"	0.50	1.00	partial	"	1
8	" /0.044	"	"	"	0.36	0.75	partial	"	2
9	" /0.044	"	"	"	0.50	0.50	partial	"	5
10	" /0.044	"	"	"	0.51	0.50	partial	"	5
11	" /0.046	"	"	1000 hrs	0.33	0.75	partial	18.3	9
12	" /0.046	"	"	"	1.59	0.50	partial	"	12
13	" /0.044	"	"	"	1.15	0.25	partial	"	15
14	" /0.044	"	"	"	0.83	0.50	partial	"	12
15	" /0.045	"	"	"	0.40	0.50	partial	"	12
16	" /0.044	"	Thermo	Humidity Cycle	-	0.50	partial	29.0	23
17	" /0.046	"	"	" "	-	1.00	partial	"	17
18	" /0.046	"	"	" "	-	0.25	partial	"	26
19	" /0.043	"	"	" "	-	1.0	partial	"	17
20	" /0.043	"	"	" "	-	0.75	partial	"	20

TABLE X INDIVIDUAL SPECIMEN DATA FOR LATERAL IMPACT TESTS

	Specimen Number	Thickness (Plies)/(In.)	Material and Orientation	Prior Conditioning Type	Prior Conditioning Duration	Moisture Weight Gain %	Energy to Failure (ft.-lb.)	Type of Fracture	Energy Req'd to Push Spec. Through Fixture (in.-lb.)	Corrected Energy to Fracture (in. lbs.)
LO	1	8 /0.041	[0°L/90°L/0°L/ 90°L/90°L/0°L/ 90°L/0°L]	None	---	--	8.00	Partial	12.7	83
	2	" /0.044	"	"	--	--	7.25	Partial	"	74
	3	" /0.040	"	"	--	--	7.75	Partial	"	80
	4	" /0.043	"	"	--	--	7.00	Partial	"	71
	5	" /0.042	"	"	--	--	7.50	Partial	"	77
	6	" /0.039	"	"	--	--	6.50	Partial	"	65
	7	" /0.042	"	"	--	--	8.50	Partial	"	89
	8	" /0.043	"	"	--	--	6.50	Partial	"	89
	9	" /0.039	"	"	--	--	6.25	Partial	"	62
	10	" /0.040	"	"	--	--	6.00	Partial	"	59
	21	" /0.040	"	98% RH	500 Hrs.	0.52	7.50	Partial	10.9	79
	22	" /0.040	"	"	"	0.83	6.50	Partial	"	91
	23	" /0.041	"	"	"	1.03	7.75	Partial	"	82
	24	" /0.040	"	"	"	0.39	6.25	Partial	"	64
	11	" /0.044	"	"	1000 Hrs.	--	--	--	-	-
	12	" /0.042	"	"	"	0.54	7.50	Partial	20.4	
	13	" /0.041	"	"	"	0.49	6.25	Partial	"	55
	14	" /0.042	"	"	"	0.47	7.00	Partial	"	64
	15	" /0.040	"	"	"	0.62	6.50	Partial	"	82
	16	" /0.043	"	Thermo-Humidity Cycle		0.44	6.00	Partial	16.2	56
	17	" /0.041	"	"	"	0.47	5.75	Partial	"	53
	18	" /0.042	"	"	"	0.27	6.50	Partial	"	86
	19	" /0.039	"	"	"	0.27	6.75	Partial	"	65
	20	" /0.040	"	"	"	0.33	7.00	Partial	"	68

TABLE X. INDIVIDUAL SPECIMEN DATA FOR LATERAL IMPACT TESTS

Specimen Number	Thickness (Plies)/(In.)	Material and Orientation	Prior Conditioning Type	Prior Conditioning Duration	Moisture Weight Gain %	Energy to Failure (ft.-lb.)	Type of Fracture	Energy Req'd to Push Spec Through Fixture (in.-lb.)	Corrected Energy to Fracture (in.-lbs.)
HY 2:1 6	8 /0.047	[0°R/90°R/0°L/ 90°L/0°R/90°R_2/ 0°R/90°L/0°L/ 90°R/0°R]	98% RH	500 Hrs.	0.29	9.00	Partial	23.2	85
7	" /0.047	"	98% RH	"	0.38	8.75	Partial	"	82
8	" /0.045	"	"	"	0.47	8.50	Partial	"	79
9	" /0.046	"	"	"	0.32	11.00	Partial	"	1
10	" /0.046	"	"	"	0.43	10.00	Partial	"	97
11	" /0.046	"	"	1000 Hrs.	0.71	9.25	Partial	11.1	100
12	" /0.045 1	"	"	"	0.53	9.50	Partial	"	103
13	" /0.046	"	"	"	0.57	8.50	Partial	"	91
14	" /0.046	"	"	"	0.64	9.97	Partial	"	109
15	" /0.047	"	"	"	0.37	10.50	Partial	"	115
16	" /0.045	"	Thermo Humidity Cycle		0.73	8.50	Partial	38.6	63
17	" /0.045	"	"	"	0.62	10.50	Partial	"	87
18	" /0.045	"	"	"	0.73	9.25	Partial	"	72
19	" /0.046	"	"	"	0.65	0.65	Partial	"	78
20	" /0.046	"	"	"	0.64	10.00	Partial	"	81

TABLE X INDIVIDUAL SPECIMEN DATA FOR LATERAL IMPACT TESTS

Specimen Number	Thickness (Plies)/(In.)	Material and Orientation	Prior Type	Conditioning Duration	Moisture Weight Gain %	Energy to Failure (ft.-lb.)	Type of Fracture	Energy Req'd to Push Spec. Through Fixture (in.-lb.)	Corrected Energy to Fracture (in.-lbs.)
LQ1 1	8 /0.047	[0°L/$\pm$45°L/90L_2/ $\mp$45°L/0°L]	None	--	--	14.00	Partial	21.3	147
2	" /0.045	"	"	--1	--1	10.50	Partial	"	105
3	" /0.045	"	"	--	--	14.00	Partial	"	147
4	" /0.045	"	"	--	--	13.50	Partial	"	141
5	" /0.045	"	"	--	--	12.25	Partial	"	126
6	" /0.045	"	"	--	--	12.50	Partial	"	129
7	" /0.046	"	"	--	--	12.50	Partial	"	129
8	" /0.047	"	"	--	--	12.00	Partial	"	123
9	" /0.044	"	"	--	--	11.00	Partial	"	111
10	" /0.043	"	"	--	--	9.00	Partial	"	87
11	" /0.045	"	98% RH	500 Hrs.	0.29	12.25	Partial	31.6	115
12	" /0.045	"	"	"	0.48	11.00	Partial	"	100
13	" /0.045	"	"	"	0.50	11.25	Partial	"	103
14	" /0.045	"	"	"	0.88	18.25	Partial	"	187
15	" /0.045	"	"	"	0.23	14.75	Partial	"	145
16	" /0.046	"	98% RH	1000 Hrs.	0.49	9.00	Partial	17.5	90
17	" /0.045	"	"	"	0.57	11.00	Partial	"	114
18	" /0.043	"	"	"	0.45	11.00	Partial	"	114
19	" /0.045	"	"	"	0.51	12.75	Partial	"	135
20	" /0.043	"	"	"	0.31	12.25	Partial	"	129
21	" /0.045	"	Thermo Humidity Cycle		0.34	9.50	Partial	22.8	91
22	" /0.043	"	"	"	0.35	11.00	Partial	"	109
23	" /0.044	"	"	"	0.36	10.00	Partial	"	97
24	" /0.045	"	"	"	0.34	10.00	Partial	"	97
25	" /0.045	"	"	"	0.35	11.00	Partial	"	109

TABLE X INDIVIDUAL SPECIMEN DATA FOR LATERAL IMPACT TESTS

Specimen Number		Thickness (Plies)/(In.)	Materials and Orientation	Prior Conditioning Type	Prior Conditioning Duration	Moisture Weight Gain %	Energy to Fracture (ft.-lb.)	Type of Failure	Energy Req'd to Push Spec. Through Fixture (in.-lb.)	Corrected Energy to Fracture (in.-lb.)
RQI	1	8 /0.041	$[0°R/\pm45°R/90°R_2/\mp45°R/0°R]$	None	--	--	4.50	Complete	--	54
	2	" /0.042	"	"	--	--	4.00	"	"	48
	3	" /0.042	"	"	--	--	3.50	"	"	42
	4	" /0.041	"	"	--	--	4.00	"	"	48
	5	" /0.042	"	"	--	--	4.75	"	"	57
	6	" /0.041	"	"	--	--	4.25	"	"	51
	7	" /0.042	"	"	--	--	4.00	"	"	48
	8	" /0.042	"	"	--	--	5.00	"	"	60
	9	" /0.041	"	"	--	--	4.00	"	"	48
	10	" /0.042	"	"	--	--	4.50	"	"	54
	11	" /0.044	"	98% RH	500 Hrs.	0.75	4.00	"	--	48
	12	" /0.044	"	"	"	1.72	4.00	"	"	48
	13	" /0.045	"	"	"	0.57	4.00	"	"	48
	14	" /0.042	"	"	"	0.53	3.75	"	"	45
	15	" /0.045	"	"	"	0.45	3.75	"	"	45
	16	" /0.045	"	98% RH	1000 Hrs.	0.70	5.00	"	"	60
	17	" /0.045	"	"	"	0.73	4.75	"	"	57
	18	" /0.045	"	"	"	0.73	4.75	"	"	57
	19	" /0.045	"	"	"	0.71	4.75	"	"	57
	20	" /0.046	"	"	"	0.69	4.75	"	"	57
	21	" /0.044	"	Thermo-Humidity Cycle		1.09	4.75	"	"	57
	22	" /0.044	"	"	"	1.15	4.50	"	"	54
	23	" /0.043	"	"	"	0.74	3.50	"	"	42
	24	" /0.044	"	"	"	1.08	4.75	"	"	57

TABLE X. INDIVIDUAL SPECIMEN DATA FOR LATERAL IMPACT TESTS

Specimen Number		Thickness (Plies)/(In.)		Material and Orientation	Prior Conditioning Type	Prior Conditioning Duration	Moisture Weight Gain %	Energy to Fracture (ft.-lb.)	Type of Failure	Energy Req'd to Push Spec Through Fixture (in.-lb.)	Corrected Energy to Fracture (in.-lbs.)
R-0	1	8	/0.045	[0°R/0°L/0°R/ 0°L_2/0°R/0°L/ 0°R]	None	--	--	--	--	--	--
	2	8	/0.052	"	"	--	--	11.75	Partial	53.4	88
	3	8	/0.055	"	"	--	--	12.5	Partial	53.4	97
	4	8	/0.052	"	"	--	--	9.5	Partial	53.4	61
	5	8	/0.053	"	"	--	--	10.00	Partial	53.4	67
R-0	6	8	/0.045	"	98% RH	500 Hrs.	.52	14.75	Partial	46.0	13
	7	8	/0.045	"	"	"	.63	12.50	Partial	46.0	104
	8	8	/0.046	"	"	"	.49	16.00	Partial	46.0	146
	9	8	/0.046	"	"	"	.65	12.00	Partial	46.0	98
	10	8	/0.047	"	"	"	.56	14.00	Partial	46.0	122
R-0	11	8	/0.045	"	98% RH+	1000 Hrs.	--	15.25	Partial	31.5	151
	12	8	/0.047	"	"	"	.57	14.00	Partial	31.5	136
	13	8	/0.045	"	"	"	.99	16.00	Partial	31.5	160
	14	8	/0.046	"	"	"	.56	18.00	Partial	31.5	184
	15	8	/0.047	"	"	"	.59	13.75	Partial	31.5	133
R-0	16	8	/0.045	"	"	"	.81	11.75	Partial	23.1	118
	17	8	/0.046	"	"	"	--	12.00	Partial	23.1	118
	18	8	/0.045	"	"	"	1.36	12.75	Partial	23.1	130
	19	8	/0.045	"	"	"	1.11	13.75	Partial	23.1	142
	20	8	/0.043	"	"	"	--	12.50	Partial	23.1	127

TABLE X INDIVIDUAL SPECIMEN DATA FOR LATERAL IMPACT TESTS

	Specimen Number	Thickness (Plies)/(In.)	Material and Orientation	Prior Conditioning Type	Prior Conditioning Duration	Moisture Weight Gain %	Energy to Fracture (ft.-lb.)	Type of Failure	Energy Req'd to Push Spec. Through Fixture (in.-lb.)	Corrected Energy to Fracture (in.-lb.)
LO	1	8 /0.044	$0°L_8$	None	--	--	17.00	Partial	52.3	152
	2	" /0.042	"	"	--	--	18.75	Partial	"	173
	3	" /0.045	"	"	--	--	17.50	Partial	"	158
	4	" /0.043	"	"	--	--	18.50	Partial	"	170
	5	" /0.043	"	"	--	--	18.75	Partial	"	173
	6	" /0.037	"	"	--	--	15.50	Partial	40.4	146
	7	" /0.040	"	"	--	--	16.00	Partial	"	152
	8	" /0.040	"	"	--	--	17.50	Partial	"	170
	9	" /0.048	"	"	--	--	17.00	Partial	"	164
	10	" /0.037	"	"	--	--	16.25	Partial	"	155
	16	" /0.040	"	98%$_6$ RH	500 Hrs.	0.49	16.50	Partial	47.1	151
	17	" /0.041	"	"	"	0.74	6.0	Partial	"	25
	18	" /0.043	"	"	"	0.79	18.25	Partial	"	172
	19	" /0.042	"	"	"	0.48	17.50	Partial	"	163
	20	" /0.042	"	"	"	0.93	18.00	Partial	"	169
	11	" /0.040	"	98%	1000 Hrs.	0.60	16.50	Partial	53.6	144
	12	" /0.043	"	"	"	0.65	17.25	Partial	"	153
	13	" /0.044	"	"	"	0.77	18.50	Partial	"	168
	14	" /0.038	"	"	"	0.82	17.50	Partial	"	168
	15	" /0.040	"	"	"	0.60	18.75	Partial	"	171
	21	" /0.042	Thermo-Humidity Cycle			0.20	17.50	Partial	93.7	116
	22	" /0.038	"	"	"	--	16.00	Partial	"	98
	23	" /0.042	"	"	"	0.30	20.00	Partial	"	146
	24	" /0.042	"	"	"	0.35	20.00	Partial	"	146
	25	" /0.042	"	"	"	--	20.25	Partial	"	152

TABLE X. INDIVIDUAL SPECIMEN DATA FOR LATERAL IMPACT TESTS

Specimen Number	Thickness (Plies)/(In.)	Material and Orientation	Prior Conditioning Type	Prior Conditioning Duration	Moisture Weight Gain %	Energy to Fracture (ft.-lb.)	Type of Failure	Energy Req'd to Push Spec Through Fixture (in.-lb.)	Corrected Energy to Fracture (in.-lbs.)
HY 2:1 1	6 /0.037	[0°R/0°L/0°R/ 0°R/0°L/0°R]	None	--	--	11.00	Partial	29.3	103
2	6 /0.036	"	"	--	--	9.25	Partial	29.3	82
3	6 /0.035	"	"	--	--	10.25	Partial	29.3	94
4	6 /0.035	"	"	--	--	9.75	Partial	29.3	94
6	6 /0.036	"	98% RH	500 Hrs.	0.68	7.50	Partial	25.6	64
7	6 /0.037	"	"	"	0.58	7.50	Partial	25.6	64
8	6 /0.036	"	"	"	0.55	7.50	Partial	25.6	64
9	6 /0.035	"	"	"	0.51	7.50	Partial	25.6	64
10	6 /0.040	"	"	"	0.68	7.75	Partial	25.6	67
11	6 /0.036	"	98% RH	1000 Hrs.	0.88	7.50	Partial	19.9	70
12	6 /0.036	"	"	"	0.30	7.00	Partial	19.9	64
13	6 /0.037	"	"	"	0.91	8.00	Partial	19.9	76
14	6 /0.037	"	"	"	0.84	7.75	Partial	19.9	73
15	6 /0.036	"	"	"	0.79	7.75	Partial	19.9	73
16	6 /0.036	"	Thermo-Humidity Cycle		0.69	7.25	Partial	21.3	66
17	6 /0.035	"	"		0.71	6.75	Partial	21.3	60
18	6 /0.037	"	"		0.75	7.50	Partial	21.3	69
19	6 /0.035	"	"		0.76	7.50	Partial	21.3	69
20	6 /0.035	"	"		0.76	8.00	Partial	21.3	75

TABLE X. INDIVIDUAL SPECIMEN DATA FOR LATERAL IMPACT TESTS

Specimen Number	Thickness (Plies)/(In.)	Material and Orientation	Prior Conditioning Type	Prior Conditioning Duration	Moisture Weight Gain %	Energy to Fracture (ft.-lb.)	Type of Failure	Energy Req'd to Push Spec Through Fixture (in.-lb.)	Corrected Energy to Fracture (in.-lb)
1	16 /0.093	[0°R/90°R/0°R/90°R/ 45°L/135°L/90°R/0°R/ 0°R/90°R/135°L/45°L/ 90°R/0°R/90°R/0°R]	None	-	-	25.00	Partial	43.7	256
2	" /0.094	"	"	"	"	22.00	Partial	"	220
3	" /0.094	"	"	"	"	28.00	Partial	"	292
4	" /0.092	"	"	"	"	26.00	Partial	"	256
5	" /0.092	"	"	"	"	28.25	Partial	"	295
6	" /0.088	"	98% RH	500 hrs	0.46	23.00	Partial	18.0	261
7	" /0.096	"	"	"	0.49	23.25	Partial	"	258
8	" /0.098	"	"	"	0.41	23.00	Complete	-	276
9	" /0.095	"	"	"	0.41	21.00	Complete	-	252
10	" -	"	"	"	-	-	-	-	-
11	" /0.095	"	"	1000 hrs	0.38	22.50	Complete	-	270
12	" /0.089	"	"	"	0.34	29.00	Partial	21.0	327
13	" /0.095	"	"	"	0.42	30.25	Complete	-	363
14	" /0.092	"	"	"	0.49	18.75	Complete	-	225
15	" -	"	"	"	-	-	-	-	-
16	" /0.091	"	Thermo Humidity Cycle		-	33.00	Partial	37.6	358
17	" /0.093	"	"	" "	"	24.75	Partial	"	259
18	" /0.092	"	"	" "	"	25.25	Partial	"	255
19	" /0.090	"	"	" "	"	37.00	Partial	"	406
20	" /0.092	"	"	" "	"	38.00	Partial		418

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